LAMONT GEOLOGICAL OBSERVATORY
COLUMBIA UNIVERSITY
PALISADES, NEW YORK

PRECISION SOUND VELOCITY PROFILES IN THE OCEAN

VOLUME IV

CANARY ISLANDS - GIBRALTAR - BAY OF BISCAY
SOUND SPEED, TEMPERATURE, ETC.
(June - July 1965)

by

Ants T. Pilp

Columbia University Geophysical Field Station
St. David's, Bermuda

Technical Report No. 6
CU-6-68

Submitted to Acoustic Programs, Office of Naval Research under Contract Nonr 266 (65).

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ABSTRACT

Detailed, consecutive sound speed and temperature profiles to 2300 m depth, and profile envelopes for each station, are presented for 26 multi-profile stations: 5 in the Canary Islands; and a near-synoptic series of 21 on a track Canaries - Gibraltar - Bay of Biscay. Sound speed, temperature and salinity (calculated from sound speed, temperature and depth) cross sections for the Canaries - Bay of Biscay part are also presented. A discussion of the spreading of Mediterranean waters from Gibraltar, and the accompanying changes in the sound speed structure is included: 1) the spreading of the Mediterranean waters has an entirely different character in the two directions. Towards the southwest the Mediterranean water soon mixes with the surroundings. Off Madeira and in the Canaries mixing is complete, temperature decreases smoothly from the surface layer downwards, without a pronounced deep thermocline. The deep salinity maximum has disappeared. Occasional large cells of Mediterranean water reach this area without mixing: one such cell is described. Towards the north, the Mediterranean water moves to 42° N without appreciable mixing, where the main body seems to veer to the west, but a good part continues into the Bay of Biscay, retaining its identity between North Atlantic surface and deep waters. 2) The sound speed structure has a uniform trend from a flat, wide sound channel reaching from 1000 to 2000 m depth in the Canaries to a distinct two-channel structure further north, the two channels becoming more sharply defined and spreading apart in depth as one goes north.

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INTRODUCTION

In summer 1965 we had an opportunity of using the cableship JOHN W. MACKAY for a velocimeter cruise in the Canary Islands, and from the Canaries to the Bay of Biscay. Good, detailed sound speed and temperature data and profiles for this area have not been obtained, or at least published, previously. To alleviate this situation and to obtain an idea of the microstructure and short-term variability of the water structure, we took several stations in the waters between and immediately to the west of the islands; and a near-synoptic series of 21 stations from about 40 miles west of Hierro to close to Gibraltar to the Bay of Biscay. Normally, two multi-profile stations were taken each day, of 2 or 4 consecutive profiles from the surface to 2300 m depth each.

The obtained profiles form a series, changing radically in shape along our track, and give a very instructive picture of the spreading of the deep Mediterranean outflow to the southwest and to the north of Gibraltar.

The track of our cruise, and the locations of our stations are given in Fig. 1.

In our list of stations, both "M-numbers" (M2-M27, "M" for MACKAY), and consecutive numbers (60-85) are assigned to each station. In the text we shall only refer to the M-numbers (there is no M1).

INSTRUMENTATION

This was our first extensive cruise with our second-generation instrumentation. A simplified block diagram is given in Fig. 2.

The underwater sensor package contains two NBS-type velocimeters (Modified TR-2) for channels 2 and 3; a FM-output precision pressure gauge for channel 1; and a FM-output platinum resistance thermometer in channel 4. Each instrument is fed by an individual voltage regulator. The instrument outputs, after suitable frequency divisions to prevent overlapping, and filtering, are combined in a summing cable driver amplifier and sent up via the single-conductor cable. The underwater package is powered from a topside constant-current DC supply through the same cable.

On shipboard the composite signal is separated into its component channels. The frequencies are multiplied by a chain of push-push doublers to four times the basic instrument frequencies. The 4 channels are scanned in a 1 - 2 - 1 - 3 - 1 - 4 sequence, a second for each channel, and the frequencies printed on paper tape.

On this cruise we used a 2-mile piece of British light undersea telephone cable as the connecting link between the submerged and shipboard part of the instrumentation. This is a very substantial 1-inch coaxial cable with an axial strength member. (The cable was left over from the cableship's last job, a cable lay between Cadiz and Tenerife.) It was walked out and in of the cable well,*) using the ship's standard cable machinery for lowering and retrieving the instrument package over the bow sheaves. Normally, during stations, the ship was turned stern first into the seas and wind and was steaming slowly astern (the ship being a piston steamship, this was no problem) to keep the ship's roll and drift at a minimum and let the cable go down as straight as possible. However, because of the lightness and large diameter of the cable and transverse deep currents, lateral wire angles up to 45° were common. The cable then was streaming out at just about right angles to the centerline of the ship.

In profiling, cable speed was controlled closely to give a depth change rate of about 1 m/s. Thus, sound speed readings were obtained about every 3.5 m, temperature every 9 m, and depth every 3 m, on the average.

Our methods of data processing ashore, and quality control, have been described in previous volumes of this series. Suffice to mention that data reduction was done on the LGO computer, yielding machine-drawn original profiles as well as numerical output data; and that the sound speed as given in the graphs is the validated average of the two velocimeter readings.

ACCURACY, CORRECTIONS TO THE PLOTS

The sound speeds in the graphs pertain to a velocimeter standardized for + 10 °C. For other ambient temperatures, the readings in the plots have to be corrected for sound path expansion effects:

$$\text{True sound speed} = V_i + \text{Correction}$$

$$\text{Correction} = 1.46 \cdot 10^{-5} (T - 10) V_i$$

where T: ambient temperature, °C

and V_i: indicated sound speed

T, °C	Correction, m/s
25	+ 0.33
20	+ 0.22
15	+ 0.11
10	± 0.00
5	- 0.11
0	- 0.22

Depths in this report are true, corrected values.

*) The cablewell crew, largely Welsh, was often singing while walking the cable. The excellent acoustics of the well and shelterdeck turned this into a very enjoyable background music for our stations.

Conservative estimates of the quality of our data are as follows:

	Total uncertainty, absolute	Reproducibility, resolution	
Sound speed	±0.15 m/s	±0.10 m/s	Note 1
Temperature	±0.05 °C	±0.03 °C	Note 2
Depth	±5m ± 1/2% ≤ ±10m	±2.5m ± 1/4% ≤ ±5m	
Salinity	±0.2 o/ooS	±0.1 o/ooS	

Note 1: Referred to standard used in laboratory calibration of velocimeters (Greenspan & Tschiegg, 1957). These tables were used as published, although it is generally believed they are too high by about 0.3 m/s (C.E. Tschiegg, NBS, 1966, personal communication).

Note 2: The temperatures in the bottom part of Station M22, deeper than 1500 m, are questionable. For a discuss'on of this, see page 8.

ORGANIZATION OF PLOTS

Our individual sound speed and temperature profiles for all 26 stations are presented in numerical order in Figures 3-54. For each station, there is a figure with the sound speed profiles, followed by the corresponding temperatures. The individual profiles have been separated by 5 m/s for sound speed, respectively 1 °C for temperature. Reference marks for each 5 m/s, respectively 5 °C, have been appended to each profile. In places where the profiles tend to overlap and cross each other (mostly in the surface thermocline), the right-hand profiles have been broken to improve legibility. In a few cases, dashing has been necessary to eliminate confusion.

The small horizontal ticks on the sound profiles are 10-minute time marks. Their depths and times are listed in the Appendix.

The four foldouts contain sequences of composite sound speed envelopes and temperature envelopes, of all profiles taken at each station. These have been divided into two groups according to station location: in and around the Canary Islands, stations M2-M6, in Figures 55 and 56; the section from west of the Canaries via Gibraltar to the Bay of Biscay, stations M7-M27, in Figures 57 and 58. In each group, the envelopes follow a reasonably south to north sequence from left to right.

A sequence of profiles, or profile envelopes, serves well to describe the conditions at each station and helps to identify regions of rapid change, but is not the best presentation for getting an overall picture of the area covered. Since this report covers an area with an extremely complex and atypical structure, in water composition, temperature, and sound speeds, we have constructed sections along our track from the Canaries to the Bay of Biscay: depths of constant sound speed, Fig. 59; and isotherms, Fig. 60. These curves are based on readings taken on the center lines of the appropriate profile envelopes.

Salinity. A salinity section is included in Fig. 61. Sound speeds are of interest to an acoustician, but for a hydrologist they are too ephemeral for identification of water masses. Salinity, being the most conservative of the usual parameters, is a more suitable label for this purpose. Temperatures alone are not sufficient, particularly in an area of variable water composition.

On the MACKAY, we did not have any facilities for measuring salinity directly. Therefore, we have reversed the usual procedure and computed salinities from our depth - temperature - sound speed values, using Wilson's tables (NavOceanO SP-58, 1962). For each profile, salinities were computed for every 100 m depth. Although the S values obtained in this fashion are not as good as from direct measurements, they are sufficient for a qualitative picture of the salinity structure.

RESULTS

In general, we shall only dwell on the major features of our results, describing qualitatively rather than quantitavely; and refer mainly to the sequences of profile envelopes and the three cross sections along our path.

I. Canary Islands (M2-M6)

The most striking, common feature of all stations within the islands and close offshore on their western shores, off La Palma, is the nearly constant-gradient temperature structure from the bottom of the surface thermocline to the maximum depth of our stations. Because of the Mediterranean waters having warmed up the region between 500-2000 m depth, by gradual mixing, there is no real deep thermocline, as in the open ocean where the deeper waters rather suddenly drop to temperatures around 5-7 °C. The surface waters around the islands are quite variable, the shape of the surface thermocline and mixing layer changes radically from station to station, within a few tens of miles, depending no doubt on local currents.

As a consequence of the constant-gradient deep temperature structure, and lack of a definite knee of a deep thermocline, the sound channel is washed out. Instead of a pronounced low-sound speed region, we find a nearly constant sound speed from somewhat less than 1000 m depth to 2000 meters, bulging slightly towards the high-speed side in the middle of this range. The minimum sound speeds in this kilometer-wide channel are of the order of 1500-1502 m/s, normally.

The profiles show a fair amount of fine structure - particularly the sound speeds, which depend on salinity in addition to temperature.

I A. A Prominent Cell of Mediterranean Water West of La Palma

Stations M2 and M4, a few miles west of the island of La Palma, show a tremendous high-temperature and high sound speed bulge right where one normally would expect to find the foot of the thermocline, between 1000 and 1500 m depth, which utterly seems to contradict the iso-sound speed picture of the other stations in the area. The contradiction is only temporary: this bulge is caused by a sharply defined mass of unadulterated Mediterranean water passing through the area. The normal water structure, with hardly any bulge, is seen at Station M3, 18 miles north of M2 and only 12 hours later.

We have mentioned the subject of "cells of strange waters" in other volumes of this series, but this particular cell here is the most clearcut specimen we have run across. There is not even any question about where the waters in this cell come from: they have travelled without losing their original composition and identity all the way from Gibraltar, a distance of at least 800 nautical miles. Any reasonable assumption of its speed along this path yields a lifetime measured in months.

In Station M2 the cell is conspicuous, but does not change much in the one hour between profiles 1 and 2. There is a slight decrease in maximum temperature, though: from 8.37 °C (1205 m depth, Profile 1) to 8.32 °C (1194 m, Profile 2).

The four consecutive profiles, both sound speed and temperature, of Station M4 show the cell moving out from under the ship: the maximum temperatures in the cell drop from 9.19 °C (1208 m depth) in Profile 1 to 8.69 °C (1139 m) in Profile 4, 3 hours later; the maximum sound speeds from 1508.7 m/s (1203 m) to 1505.6 m/s (1180 m). A quick check, based on sound speed and temperature excesses over the "mouth" of the bulge, shows the core of the cell at M4/1 to have a salinity of nearly 36.1 o/oo, i.e. 0.7 o/oo higher than the norm at the site.

In all probability, this cell is moving in a more or less southerly direction, having reached the area west of La Palma through the gap between the Canaries and Madeira. If so, its northern boundary had already passed the site of our Station M3 at the time of our profilings, and we see its tail in Station M2. M4 is right on the northern boundary of the cell. The 8 miles and somewhat less than 60 hours separation between M2 and M4 gives us an estimate of its minimum southerly speed between these 2 stations: 0.14 knots (7.5 cm/s).

Unfortunately, our data is insufficient to make a good estimate of the lateral dimensions of this cell, although some speculation is possible.

There are indications of a bulge, at around 1200 m depth, in profiles belonging to Stations M5, M6 and M7, 10-11 days after M4. If we interpret these faint bulges in M6 and M7 as being caused by the extreme edges of the same cell as in M2 and M4 - a not unreasonable assumption considering the distances and time separations between stations - a maximum east-west diameter of the cell of close to 100 miles is arrived at. The sharply defined core proper, however, must be appreciable smaller, maybe less than half of this.

M5 does not fit very well into this reasoning (60 miles north of M6, and 24 hours earlier). It might be a localized water mass, remaining between the islands from the edge of the main cell: e.g., in a deep eddy. The same might be applicable to M6: Hierro can easily have broken up a large cell in its southward migration, or a southwesterly deep current (probable, but no data available) between La Palma and Hierro can have swept our cell out towards M7. In this case, M5 and M6 would not be connected parts of the cell.

II. Canaries - Gibraltar (M7-M18)

The general trend in this region is for the very wide sound channel near the Canary Islands to split into a double one as one proceeds towards Gibraltar. The temperature profiles over the same route change from a nearly constant-gradient deep structure to a pronounced S-shape, due to the nearly isothermal Mediterranean outflow warming up the depths between 700-1300 m. But a closer look at Figures 57 to 61 shows that this region can be divided into 3 distinct parts, with abrupt transitions from one to the other.

A. Canaries - Madeira (M7-M13).

This region looks very much like the Canaries proper. The first 4 stations, M7-M10, really belong to the Canary Islands, and all comments made previously about the temperature, sound speed and water structures apply without modification.

Looking at the whole region, a very gradual change in the appearance of the profiles can be discerned. At the southernmost edge of the region, the nearly constant-sound speed channel at 800-1700 m depths shows a knee at 800 m, and very gradually increasing sound speed at increasing depth. This upper knee tends to sink deeper and get rounder as one goes further north, the sound speeds at the minimum increase gradually, until near Madeira the whole profile is slanting in an opposite direction, the sound speed minimum having sunk from 800 to 1800 m depth. Fine structure and short-time variability are quite uniformly distributed all over the wide sound channel - there is no rapid decrease at around a kilometer's depth, as is usual on the western side of the Atlantic. Near the surface in summer one finds a slight positive sound speed-depth gradient, followed by a sharp knee at the surface thermocline at roughly 50 m depth.

The temperature profiles are nearly straight from the bottom to 800-600 meters, all slightly concave towards the right. This curvature continues smoothly all the way to the surface thermocline. There is considerable patchiness at the foot of the surface thermocline. The surface waters very gradually get cooler towards the north.

In this region, the mixture of Mediterranean and Atlantic waters has produced a very smooth, uniform transition from the surface down to deep bottom waters. Occasional, sharply defined cells of Mediterranean waters, as at M2-M4, can complicate this simple picture.

The southernmost stations of this area must be close to another transition into a region of different character, closer to the Mid-Atlantic norm, with a pronounced deep thermocline and sound channel at a kilometer's depth. This is indicated by the abrupt rise of the near-surface isosalines between stations M7-M9, and the rapid sound speed, salinity and temperature decreases between 500 and 1500-2000 m depths.

B. Madeira - Cape Cantin (M14-M16). This is a transition region between the relatively smooth waters of Canaries-Madeira, and the Gibraltar region where the Mediterranean deep waters pouring out through the Straits have not yet lost their individuality. In this region, mixing of the Mediterranean and Atlantic waters takes place. It is characterized by smoothly S-shaped deep temperature profiles, and a very variable but definitely double sound channel. The lower half of this double channel has a smooth, rounded transition into the intermediate sound speed maximum at 1200-1300 m depth, in the barely diluted Mediterranean water. The upper channel is extremely variable. The sound speed minimum is well rounded, often patchy, but stays at around 600-800 m depth.

The deep mixing of the Mediterranean and Atlantic waters does not seem to be a uniformly gradual or smooth process. Fingers - or layers - of the different waters interleave, sometimes leaving large cells unmixed. The sharp bulge in M14 looks like another large cell in the offing: its shape and temperature and maximum sound speed are very similar to the La Palma cell (M4), although it is as yet slightly deeper.

The surface waters in this area are still similar to the Canaries area, although they have acquired a constant sound speed character. Just under the surface thermocline, between 50 and 200 m depth, is another region of pronounced patchiness (e.g., sharp kink at M15).

C. Gibraltar Area (Cape Cantin - Gibraltar, M17-M18). Here, about 100 n. miles off the Straits, one meets the deep Mediterranean outflow at full strength. The lower boundary of the Mediterranean water mass is still sharply defined, the upper boundary is very confused and patchy, with large cells forming and separating.

The deep sound speed maximum in the profiles is getting more and more pronounced, it has a sharp lower boundary, and a more gradual, but very variable and layered transition into the shallow sound channel. Temperature profiles at these depths, 700-1300 m, are very jagged, nearly isothermal at close to 10 °C. The sharp sound speed and temperature bulges at 700-800 m depth at the two stations are caused by a sharp rise of the isosaline contours, and the development of a warm water "finger" or cell - a transient phenomenon.

The surface thermocline is rapidly lengthening. The near-surface waters are no longer isothermal, but tend to get cooler with increasing depth. Also, the foot of the thermocline is better defined than further south.

III. Gibraltar - Bay of Biscay (M18-M27)

Going north from Gibraltar the picture is considerably simpler than in the opposite direction. The Mediterranean waters, between 1 and 1.5 km depth, retain their identity all the way to the Bay of Biscay, with only slight mixing and cooling. Consequently, the sound speed structure shows a double sound channel everywhere, and the temperature profiles all have a more-or-less mild "S"-shape, with a drooping tail at greater depths. Even so, again three sharply distinct areas can be distinguished, each of different character.

A. Gibraltar Area (Gibraltar - Cape St. Vincent, M18-M20). This really is an extension of the last area considered, north from Cape Cantin. The whole region from Cape Cnatin to Cape St. Vincent, i.e. the large unnamed bay bounded by the Iberian Peninsula, Gibraltar, and Africa, forms one hydrological entity. All comments made in II C apply, with the exception of the lower boundary of the intermediate, Mediterranean, sound speed maximum at 1200-1300 m depth, which is quite rounded, without a sharp boundary. The depth and shape of this sound speed maximum, and the v-.ue of the maximum sound speed in it, are probably quite variable in the whole Gibraltar area: the 10 °C isotherm here is extremely uneven, bulging up and down in great waves and cells. The isosalines and sound speed contours do the same. All this seems to indicate instability; appreciable changes might occur in days or weeks.

B. West of Portugal (Cape St. Vincent - Vigo, M21-M23). Another transition region, characterized mainly by a drop of the 10 °C isotherm to beyond 1000 m, the straightening of temperature profiles between a few hundred and 1000 meters depth, and a conspicuous sharpening of the foot of the surface thermocline. The Mediterranean water mass is moving northwards, very gradually mixing with the waters above it, and spreading slowly upward. At shallower depths, the cool but light North Atlantic surface waters gradually become dominant. Likewise, cool North Atlantic deep waters are gaining ascendancy below 1500 m.

The bottom part of Station M22, deeper than 1500 m (dashed in the plots), presents an enigma. The down and up temperature profiles track to within 0.05 °C, but compared to the deep temperatures of the neighbor stations M21 and M23 they are about 0.5 °C too low. This also shows up in our salinity section, Fig. 61, as an abnormally saline deep water at M22. The salinity is close to

Mediterranean, but the temperature is too low by far, lower than the surroundings - where could such a large cell of water originate? There is no reason to assume it is a local phenomenon. Although we cannot explain the apparently transient pressure sensitivity of our thermometer at this station, we must accept this as a likely reason for the curious data at M22.

The sound speed profiles still are similar in shape to those around Gibraltar, but differ in detail. The upper sound channel is appreciably narrower, closer to the surface (at about 300 m), and has a minimum sound speed of 1503-1504 m/s, about a m/s or two lower than off Gibraltar. The intermediate high sound speed region is much wider, has a more prominent bulge around 1200-1300 m, a higher sound speed maximum, and more clearly defined boundaries than before. The deep sound channel remains at 1700-1800 m depth, but gets rapidly sharper and slower in axis sound speed towards the north.

The length of the surface thermocline has not changed much since Gibraltar, although the surface mixing layer is getting shallower.

<u>C. Bay of Biscay (M24-M27).</u> Somewhere just west of the Portuguese-Spanish border, south of Finisterre and the 565 m seamount 100 miles west of it, the main body of Mediterranean waters veers off in a westerly direction, towards the open Atlantic. It is pushed out this way by the southward intrusion of less saline, but cold and heavy North Atlantic water at depths below 1300 m. Between our stations M23 and M24 lies an interesting region of deep confluence, worth further study.

A part of the Mediterranean waters, after slight dilution and considerable cooling, continues further north and forms a stable salinity and sound speed maximum at a kilometer's depth.

The transition from warm southern to cool northern waters in the upper sound channel, at a few hundred meters depth, is not quite as abrupt as at a depth of a kilometer. The channel changes gradually from a wide, round one to a very pointed shape at approximately 100 m depth. This gradual change in the sound speed minimum is caused both by a gradual decrease of salinity and cooling of the water under the surface thermocline. The final shape is not attained until our M25, north west of Finisterre.

The temperature profiles in the Bay of Biscay are rather striking in shape between 100 and 1000 m: straight lines, dropping only 2° (from 12 to 10 °C) over this interval. Likewise, the sound speed profiles are ruler-straight in the same interval, except for microstructure.

At depths greater than the intermediate sound speed maximum, the deep sound channel has not changed much since off Portugal: it has stabilized after its axis has risen to 1700 m and the axis speed has decreased by a few m/s, to around 1499 m/s. It is now wholly situated in North Atlantic deep waters.

Since Portugal, the surface waters have rapidly cooled, the length of the surface thermocline increased, and the mixing layer depth decreased.

It might be of interest to note that a sound speed structure identical to the one in the Bay of Biscay is found 500 n. miles west of our M27: on 4 and 5 August 1964, the Woods Hole R/V CHAIN took several velocimeter stations at roughly 46° 30' N, between 15° and 18° W and obtained profiles just like ours in the Bay. They found the deep sound channel more variable at their sites than ours (R. Payne, WHOI, personal communication).

IV. Fine Structure, Stability and Variability

A look at our sequences of profile envelopes shows that the large-scale fine structure is concentrated mainly in and close to the Gibraltar area, close to the source of the Mediterranean water mass. In this area very numerous bulges, i.e. layers and cells of different waters are evident on the sound speed profiles. Their vertical dimensions range all the way up from a few tens of meters to several hundred meters. In their vertical distribution, these large cells are most common at depths where the sound speed-depth gradients are large, along the boundaries of the different water masses mixing. Very few appear in the surface mixing layer or below the Mediterranean water mass, below 1500 m, or along the axes of the two sound channels.

A comparison of the appropriate individual sound speed and temperature profiles indicates that the large bulges in the sound speeds are always accompanied by a corresponding bulge in the temperature structure. However, the bulge in temperatures is not sufficient to cause all of the sound speed difference*): there is even a salinity difference involved. In other words, the large bulges in the profiles are caused by true cells and layers of waters of different composition.

The apparent duration of these large cells in our stations is hours, they persist over a whole station as a rule, gradually changing in shape. We do not have enough information for a good estimate of their lateral dimensions, although several cells seem to reach from one station to the other, at slightly different depths.

The real microstructure, layers and cells of thicknesses from a few tens of meters downwards until they are masked by the resolution of our profiles, are distributed more or less uniformly over our whole route: there is not very much real difference in the width of all our profile envelopes (not forgetting that some of our stations consist of 4, some of only 2 profiles), or in the amplitudes of the fine waviness on the individual profiles. The fine structure is most prominent and variable, as usual, at the same depths where the large cells

*) 1 m/s ≈ 0.28 °C ≈ 0.71 o/oo S. In our profiles, a sound speed bulge is fully caused by temperature difference if the corresponding temperature and sound speed excursions are in a ratio of 0.56, in length measure.

appear most frequently, in boundaries of water masses, or regions of high sound speed or temperature gradients.

Layer or cell thicknesses of a few tens of meters seem to be most frequent. Sound speed variations of less than 1/3 - 1/2 m/s across such a layer seem to be the norm, somewhat higher in regions of steep gradients, where occasionally a m/s or more is encountered. Since the depth resolution of our temperature profiles is only half as good as that of the sound speeds, we cannot always find direct correspondence in the two fine structures, nor really decide whether it is caused by only temperature, or both temperature and salinity variations. There are indications of both cases, though.

Most of this microstructure is not very persistent: the wiggles are continuously changing from one profile to the next, in a matter of less than hours. The lateral dimensions of the cells cannot be more than a few hundred meters across.

Since there is no noticeable difference in the vertical wavelengths of the small wiggles on our down and upgoing sound speed profiles, the vertical motions of the cells or of major features of the water masses (i.e. vertical components of internal waves) must be slow compared to our profiling speed, about 1 m/s - otherwise a Doppler shift would be evident.

Our salinity section, Fig. 61, seems to indicate a probable very large-scale (seasonal?) variability of the mass of Mediterranean water leaving Gibraltar: the concentration of Mediterranean water, both in bulk and in salinity, is much higher west of Portugal (Stations M20-M23) than directly in front of the Straits (M17-M19). This can only be caused by a much larger outflow from Gibraltar during a period some time before our measurements in the area.

SUMMARY, CONCLUSIONS

Our results illustrate two striking aspects of the Atlantic Ocean from the Canaries north to the Bay of Biscay: firstly, the spreading of Mediterranean waters has an entirely different character in southwesterly and northerly directions from Gibraltar; secondly, the sound speed structure over this whole section has a uniform trend from a kilometer-wide, nearly constant speed sound channel at the Canaries to a two-channel structure, the two channels getting more and more sharply defined and spreading further apart in depth as one goes north.

For roughly 200 miles west of the Straits the Mediterranean water stays in a compact mass between 1000 and 1500 m depth. It is beginning to break up at its upper boundary, forming large cells and thick, interleaving layers.

On its way to the southwest, the Mediterranean water soon mixes with surrounding waters. Off Madeira and in the Canaries, mixing is nearly complete, the salinity maximum between 1000 and 1500 is nearly gone, and the temperature decreases smoothly from the surface mixing layer downwards, without a true, deep thermocline. The two fairly wide, pronounced sound channels found near

Gibraltar have fused into one very flat minimum.

Occasional sharply defined cells of Mediterranean water survive the passage to the Canaries without mixing and dilution, and cause a temporary, local doubling of the sound channel in the area.

On the way north along the coast of the Iberian Peninsula, the Mediterranean water mass never loses its identity. It gradually rises a few hundred meters, until the main body turns westward around 42° N. A good part, after rapid cooling of a few degrees C and slight dilution in a narrow region south of Finisterre, continues into the Bay of Biscay, sandwiched between less saline North Atlantic surface and deep waters. In the Bay of Biscay, the temperature structure has acquired a sectionally linear character, and the two rounded sound channels of Gibraltar have become pointed in shape.

Before concluding, it might be interesting to point out the close similarity of the sound speed and salinity sections from the Canaries to the Bay of Biscay (particularly around the core of the Mediterranean waters, and at shallow depths), and the dissimilarity of the sound speed and temperature sections. This could serve as an illustration of the hazards of using temperature data alone for sound speed predictions in areas of changing water composition.

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REFERENCES

M. Greenspan and C.E. Tschiegg, 1957: "Speed of Sound in Water by a Direct Method," J. Res. Nat. Bur. Stds. 59, 249.

NavOceanO SP-58, 1962: Special Publication, SP-58, August 1962. Tables of Sound Speed in Sea Water. Oceanographic Analysis Division, Marine Sciences Department. U.S. Naval Oceanographic Office, Washington, D.C. 20390.

LIST OF STATIONS

STATION NUMBER	POSITION North	West	WATER DEPTH	DATE, 1965	# OF PROF.	SOUND SPEED PROFILES	TEMPERATURE PROFILES
M 2 (60)	28°30'	18°07'	2650m	26 June	2	Fig. 3	Fig. 4
18 nautical miles between stations							
M 3 (61)	28°48'	18°09'	2880	26 June	4	Fig. 5	Fig. 6
24 n. miles							
M 4 (62)	28°25'	18°05'	3010	28 June	4	Fig. 7	Fig. 8
54 n. miles							
M 5 (63)	28°33'	17°12'	2770	6 July	2	Fig. 9	Fig. 10
51 n. miles							
M 6 (64)	27°36'	17°12'	3690	8 July	4	Fig. 11	Fig. 12
109 n. miles							
M 7 (65)	27°40'	19°00'	4240	9 July	2	Fig. 13	Fig. 14
29 n. miles							
M 8 (66)	28°14'	19°02'	4340	9 July	4	Fig. 15	Fig. 16
31 n. miles							
M 9 (67)	28°42'	19°00'	4450	9 July	4	Fig. 17	Fig. 18
35 n. miles							
M 10 (68)	29°20'	18°56'	4570	10 July	4	Fig. 19	Fig. 20
57 n. miles							
M 11 (69)	30°13'	18°58'	4770	10 July	4	Fig. 21	Fig. 22
110 n. miles							
M 12 (70)	31°06'	17°00'	4540	11 July	4	Fig. 23	Fig. 24
80 n. miles							
M 13 (71)	31°45'	15°33'	4490	11 July	2	Fig. 25	Fig. 26
105 n. miles							
M 14 (72)	32°35'	13°47'	4380	12 July	4	Fig. 27	Fig. 28
80 n. miles							

LIST OF STATIONS (Cont.)

STATION NUMBER	POSITION North	POSITION West	WATER DEPTH	DATE, 1965	# OF PROF.	SOUND SPEED PROFILES	TEMPERATURE PROFILES
M 15 (73)	33°10'	12°15'	4160	12 July	2	Fig. 29	Fig. 30
110 n. miles							
M 16 (74)	34°00'	10°20'	4440	13 July	4	Fig. 31	Fig. 32
90 n. miles							
M 17 (75)	34°47'	08°48'	3500	13 July	2	Fig. 33	Fig. 34
57 n. miles							
M 18 (76)	35°16'	07°47'	1910	14 July	2	Fig. 35	Fig. 36
63 n. miles							
M 19 (77)	35°56'	08°54'	3630	14 July	2	Fig. 37	Fig. 38
47 n. miles							
M 20 (78)	36°24'	09°42'	3750	14 July	2	Fig. 39	Fig. 40
103 n. miles							
M 21 (79)	38°00'	10°45'	5050	15 July	4	Fig. 41	Fig. 42
98 n. miles							
M 22 (80)	39°29'	11°03'	4660	15 July	2	Fig. 43	Fig. 44
100 n. miles							
M 23 (81)	41°08'	10°48'	3750	16 July	2	Fig. 45	Fig. 46
92 n. miles							
M 24 (82)	42°42'	10°30'	2690	16 July	2	Fig. 47	Fig. 48
110 n. miles							
M 25 (83)	44°27'	10°03'	5040	17 July	2	Fig. 49	Fig. 50
92 n. miles							
M 26 (84)	45°02'	08°00'	4450	17 July	2	Fig. 51	Fig. 52
95 n. miles							
M 27 (85)	46°08'	06°18'	4800	18 July	2	Fig. 53	Fig. 54

APPENDIX
Timing of Profiles

Profile	D(m)	GMT
M2/1	9	0710
	324	0720
	787	0730
	1244	0740
	1689	0750
	2072	0800
	2150	0805
M2/2	2143	0806
	2047	0810
	1581	0820
	1027	0830
	565	0840
	122	0850
	3	0858
M3/1	2	2028
	31	2030
	415	2040
	795	2050
	1463	2100
	1951	2110
	2244	2118
M3/2	2229	2120
	1772	2130
	1262	2140
	742	2150
	275	2200
	9	2206
M3/3	8	2207
	85	2210
	426	2220
	898	2230
	1340	2240
	1714	2250
	2008	2300
	2248	2307
M3/4	2211	2310
	1748	2320
	1223	2330
	801	2340
	541	2350
	217	2400
	1	0010
M4/1	1	1916
	135	1920
	578	1930
	1046	1940
	1527	1950
	1998	2000
	2249	2006
M4/2	2239	2010
	1918	2020
	1441	2030
	991	2040
	526	2050
	65	2100
	1	2104
M4/3	2	2105
	194	2110
	636	2120
	1081	2130
	1538	2140
	1993	2150
	2247	2155
M4/4	2243	2200
	1874	2210
	1468	2220
	1030	2230
	548	2240
	115	2250
	1	2254
M5/1	2	1953
	206	2000
	912	2020
	1201	2030
	1502	2040
	1815	2050
	2120	2100
	2253	2105
M5/2	2245	2106
	2118	2110
	1666	2120
	1284	2130
	935	2140
	652	2150
	346	2200
	111	2210
	1	2215
M6/1	2	1746
	110	1750
	554	1800
	1031	1810
	1435	1820
	1773	1830
	2028	1840
	2242	1845
M6/2	2213	1847
	2119	1850
	1747	1900
	1404	1910
	1040	1920
	781	1930
	349	1940
	1	1947
M6/3	3	1948
	53	1950
	498	2000
	990	2010
	1421	2020
	1820	2030
	2222	2040
	2261	2041
M6/4	2260	2042
	2020	2050
	1623	2100
	1166	2110
	761	2120
	327	2130
	1	2138
M7/1	1	0809
	5	0810
	345	0820
	866	0830
	1349	0840
	1815	0850
	2278	0859
M7/2	2254	0903
	1991	0910
	1564	0920
	1137	0930
	686	0940
	163	0950
	4	0952
M8/1	5	1350
	307	1400
	500	1410
	885	1420
	1096	1430
	1507	1440
	1889	1450
	2239	1500
M8/2	2238	1502
	1871	1510
	1431	1520
	1126	1530
	776	1540
	324	1550
	92	1600
	3	1602
M8/3	4	1603
	245	1610
	730	1620
	1146	1630
	1509	1640
	2035	1650
	2242	1654
M8/4	2242	1656
	2120	1700
	1698	1710
	1209	1720
	724	1730
	261	1740
	1	1748
M9/1	3	2037
	115	2040
	580	2050
	1055	2100
	1491	2110
	1934	2120
	2240	2127
M9/2	2241	2128
	2197	2130
	1824	2140
	1433	2150
	945	2200
	440	2210
	1	2218
M9/3	1	2220
	398	2230
	899	2240
	1374	2250
	1831	2300
	2264	2310
	2301	2311
M9/4	2305	2312
	2025	2320
	1612	2330
	1144	2340
	661	2350
	159	2400
	1	0006

APPENDIX (Cont.)
Timing of Profiles

Profile	D(m)	GMT
M10/1	2	0806
	196	0810
	641	0820
	1128	0830
	1616	0840
	2039	0850
	2245	0855
M10/2	2245	0856
	2134	0900
	1720	0910
	1254	0920
	784	0930
	278	0940
	1	0948
M10/3	1	0949
	35	0950
	505	1000
	965	1010
	1450	1020
	1900	1030
	2240	1037
M10/4	2239	1038
	2192	1040
	1782	1050
	1319	1100
	813	1110
	338	1120
	1	1128
M11/1	8	1717
	89	1720
	505	1730
	973	1740
	1466	1750
	1882	1800
	2242	1808
M11/2	2253	1809
	2234	1810
	1878	1820
	1412	1830
	895	1840
	403	1850
	1	1858
M11/3	1	1859
	16	1900
	452	1910
	973	1920
	1481	1930
	1976	1940
	2244	1946

Profile	D(m)	GMT
M11/4	2244	1947
	2139	1950
	1663	2000
	1186	2010
	725	2020
	238	2030
	1	2035
M12/1	5	0804
	128	0810
	589	0820
	898	0830
	1339	0840
	1791	0850
	2207	0900
	2242	0901
M12/2	2243	0904
	2013	0910
	1562	0920
	1126	0930
	768	0940
	378	0950
	1	0959
M12/3	1	1000
	337	1010
	818	1020
	1264	1030
	1688	1040
	2095	1050
	2300	1056
M12/4	2300	1057
	2214	1100
	1782	1110
	1393	1120
	1011	1130
	587	1140
	188	1150
	1	1155
M13/1	4	2005
	167	2010
	535	2020
	972	2030
	1412	2040
	1869	2050
	2231	2100
	2301	2101

Profile	D(m)	GMT
M13/2	2304	2103
	2110	2110
	1715	2120
	1286	2130
	816	2140
	347	2150
	1	2158
M14/1	3	0806
	152	0810
	518	0820
	1031	0830
	1463	0840
	1882	0850
	2295	0900
M14/2	2291	0901
	1860	0910
	1421	0920
	978	0930
	561	0940
	102	0950
	1	0952
M14/3	1	0954
	265	1000
	686	1010
	1113	1020
	1545	1030
	1973	1040
	2305	1048
M14/4	2306	1049
	2273	1050
	1898	1100
	1498	1110
	1065	1120
	626	1130
	205	1140
	1	1145
M15/1	2	2008
	80	2010
	423	2020
	852	2030
	1271	2040
	1737	2050
	2139	2100
	2297	2104

Profile	D(m)	GMT
M15/2	2293	2105
	2094	2110
	1576	2120
	1162	2130
	846	2140
	376	2150
	1	2158
M16/1	1	0825
	182	0830
	593	0840
	1042	0850
	1534	0900
	1958	0910
	2300	0918
M16/2	2299	0919
	2271	0920
	1905	0930
	1449	0940
	1035	0950
	586	1000
	81	1010
	1	1012
M16/3	4	1013
	248	1020
	702	1030
	1166	1040
	1551	1050
	1931	1100
	2297	1108
M16/4	2301	1109
	2260	1110
	1977	1120
	1557	1130
	1040	1140
	492	1150
	42	1200
	1	1201
M17/1	1	2009
	23	2010
	423	2020
	874	2030
	1339	2040
	1790	2050
	2256	2100
	2295	2102

APPENDIX (Cont.)
Timing of Profiles

Profile	D(m)	GMT
M17/2	2293	2103
	2011	2110
	1583	2120
	1136	2130
	692	2140
	205	2150
	1	2154
M18/1	1	0445
	16	0450
	340	0500
	788	0510
	1200	0520
	1603	0530
	1839	0540
	1875	0542
M18/2	1874	0543
	1572	0550
	1137	0600
	743	0610
	383	0620
	1	0629
M19/1	31	1344
	312	1350
	670	1400
	1184	1410
	1650	1420
	2102	1430
	2305	1435
M19/2	2301	1436
	2166	1440
	1734	1450
	1287	1500
	822	1510
	341	1520
	1	1529
M20/1	1	2005
	132	2010
	564	2020
	1030	2030
	1476	2040
	1919	2050
	2306	2058
M20/2	2303	2059
	2283	2100
	1906	2110
	1469	2120
	1020	2130
	559	2140
	116	2150
	1	2154
M21/1	3	0807
	83	0810
	531	0820
	958	0830
	1392	0840
	1884	0850
	2283	0859
M21/2	2295	0900
	1866	0910
	1412	0920
	943	0930
	454	0940
	4	0949
M21/3	2	0950
	426	1000
	875	1010
	1370	1020
	1832	1030
	2292	1040
M21/4	2295	1041
	1916	1050
	1479	1100
	1031	1110
	546	1120
	65	1130
	1	1131
M22/1	4	2010
	440	2020
	891	2030
	1350	2040
	1798	2050
	2231	2100
	2306	2101
M22/2	2307	2102
	2016	2110
	1577	2120
	1132	2130
	670	2140
	177	2150
	1	2155
M23/1	1	0815
	249	0820
	701	0830
	1166	0840
	1588	0850
	2042	0900
	2301	0906
M23/2	2302	0907
	2155	0910
	1712	0920
	1270	0930
	812	0940
	394	0950
	26	1000
M24/1	1	2006
	96	2010
	583	2020
	1004	2030
	1410	2040
	1867	2050
	2236	2057
M24/2	2230	2100
	1775	2110
	1332	2120
	813	2130
	386	2140
	1	2149
M25/1	3	0809
	10	0810
	414	0820
	775	0830
	1269	0840
	1659	0850
	2142	0900
	2295	0902
M25/2	2292	0903
	1850	0910
	1434	0920
	1066	0930
	676	0940
	248	0950
	1	0955
M26/1	2	2006
	106	2010
	520	2020
	841	2030
	1307	2040
	1781	2050
	2237	2100
	2299	2102
M26/2	2291	2103
	2054	2110
	1495	2120
	1057	2130
	591	2140
	150	2150
	1	2153
M27/1	1	0809
	6	0810
	448	0820
	927	0830
	1426	0840
	1875	0850
	2295	0900
M27/2	2298	0901
	1914	0910
	1466	0920
	975	0930
	479	0940
	1	0949

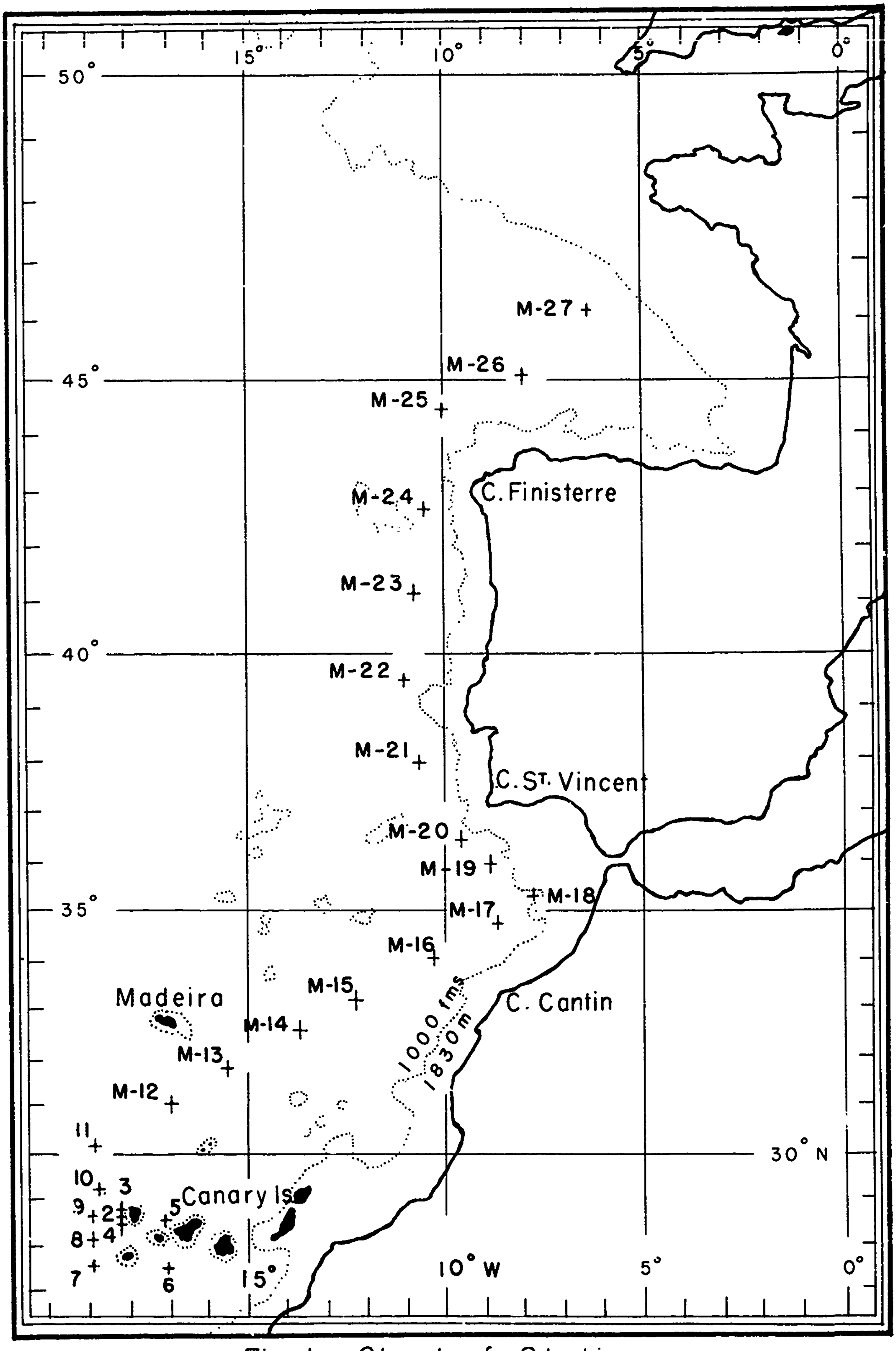


Fig. I Chart of Stations

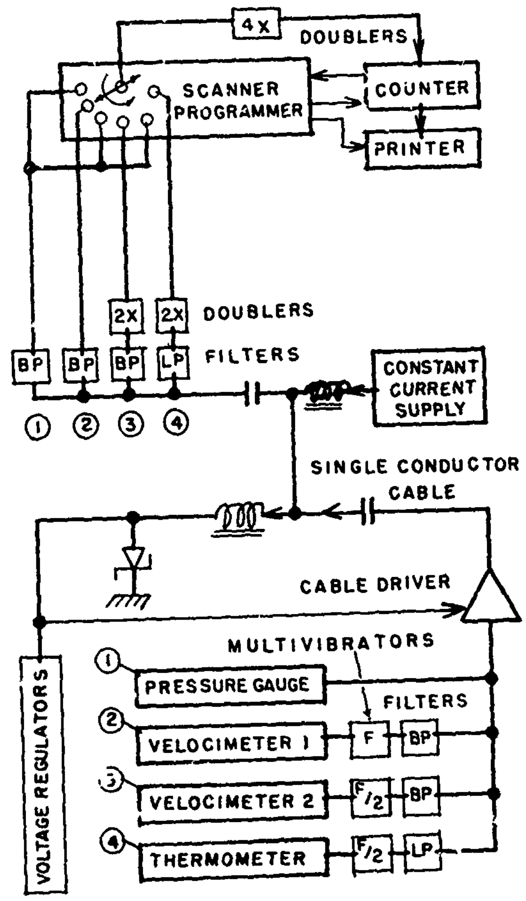


Fig. 2 *Block diagram of Instrumentation*

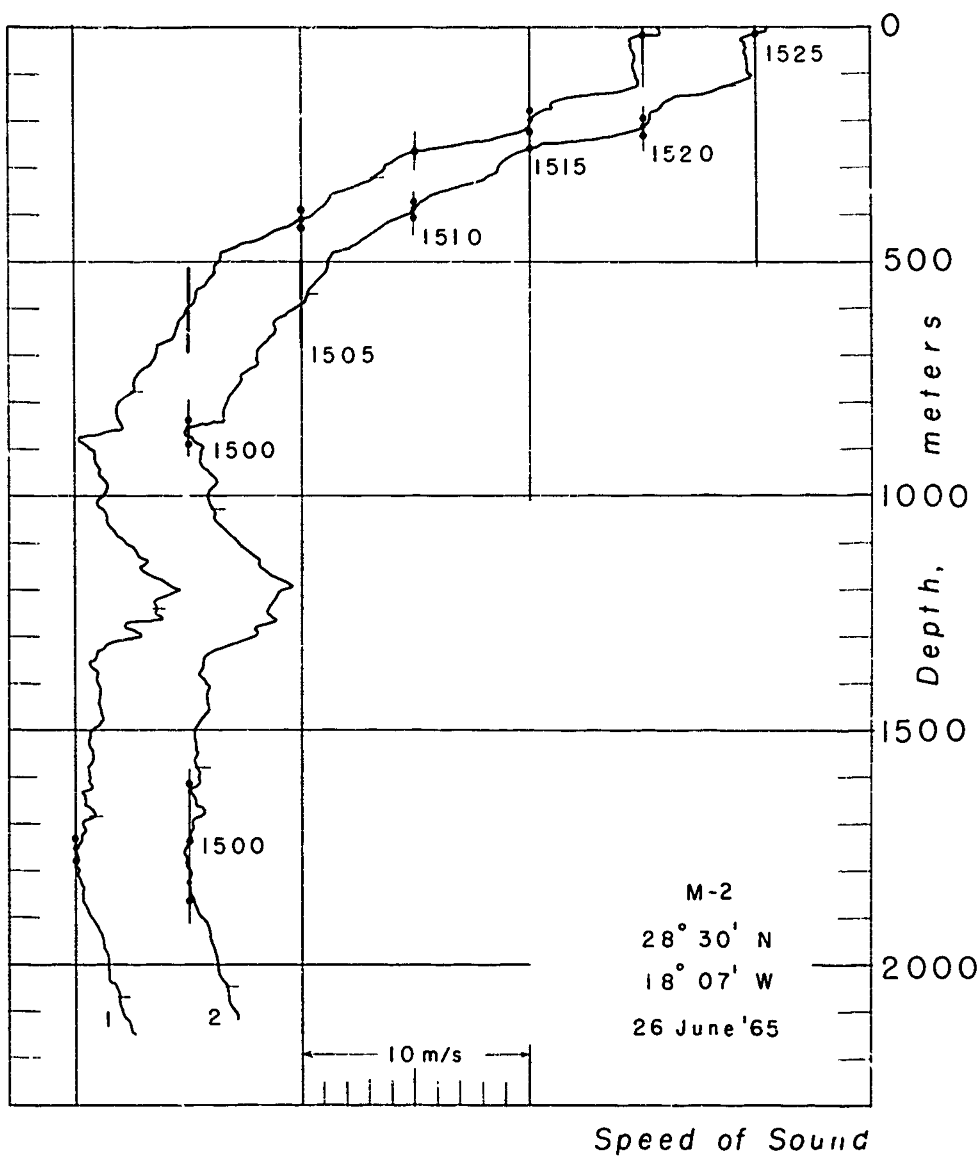


Fig. 3 *Sound Speeds* - Station M-2

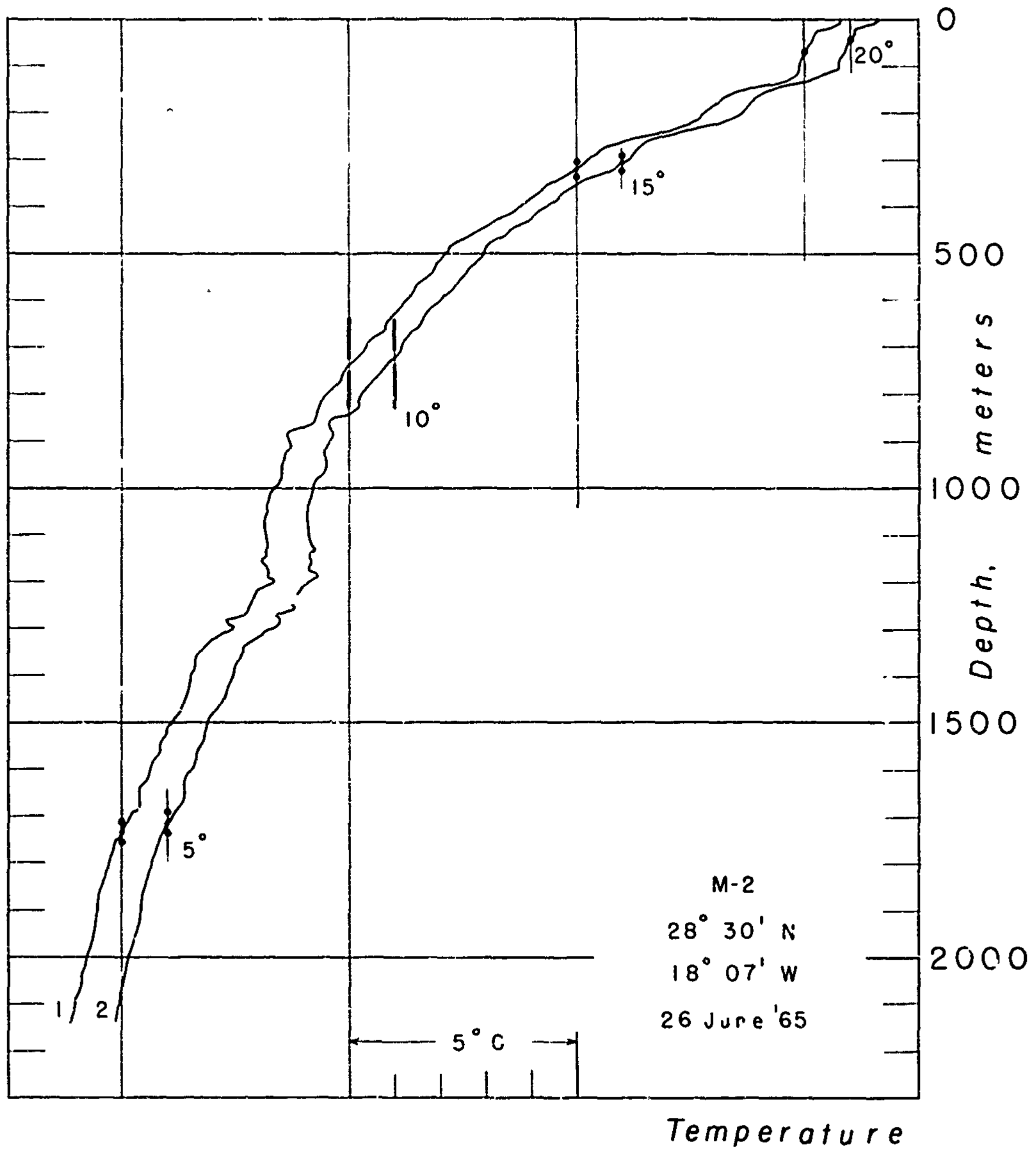


Fig. 4 *Temperatures* - Station M-2

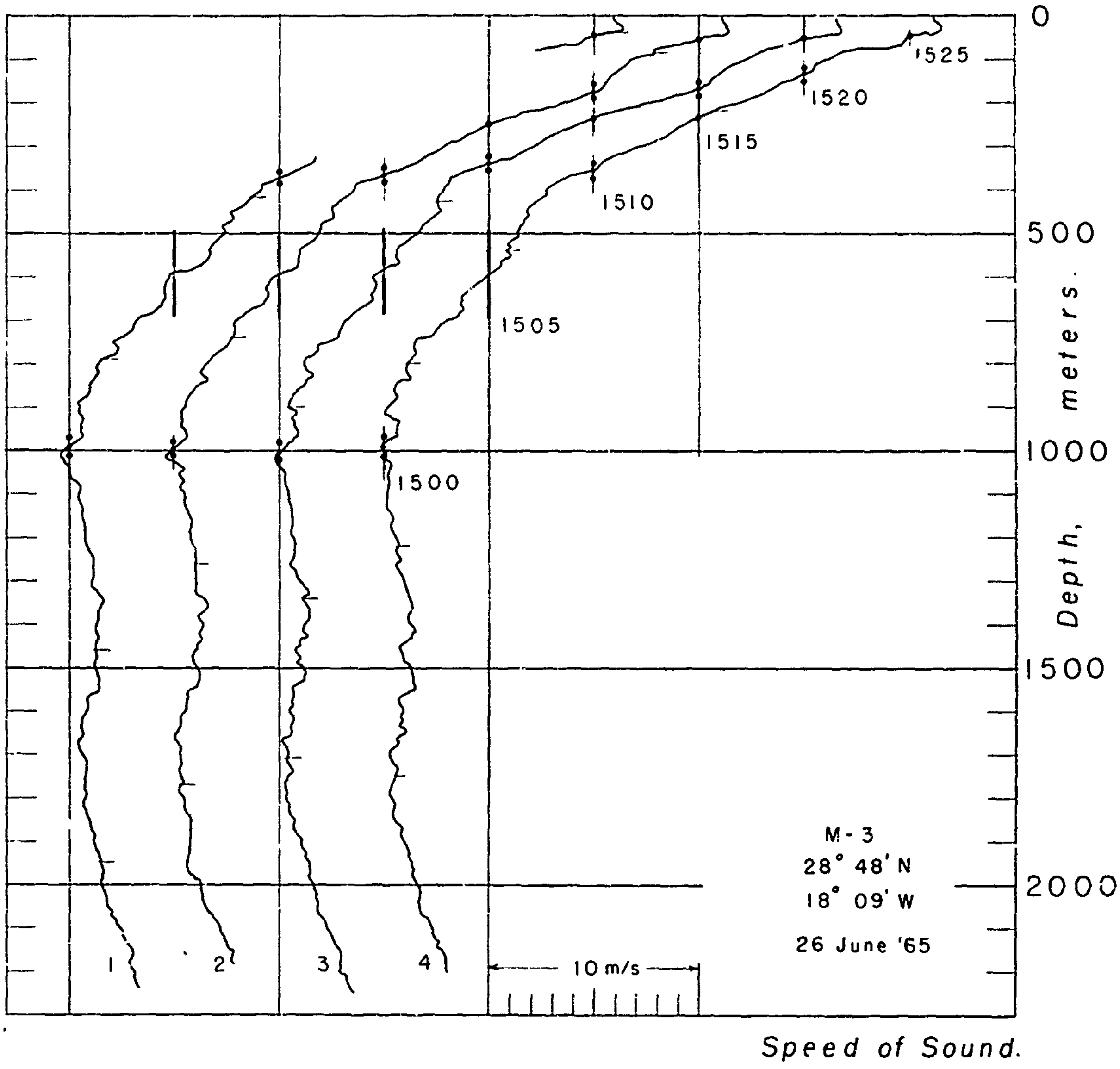


Fig. 5 Sound Speeds - Station M-3

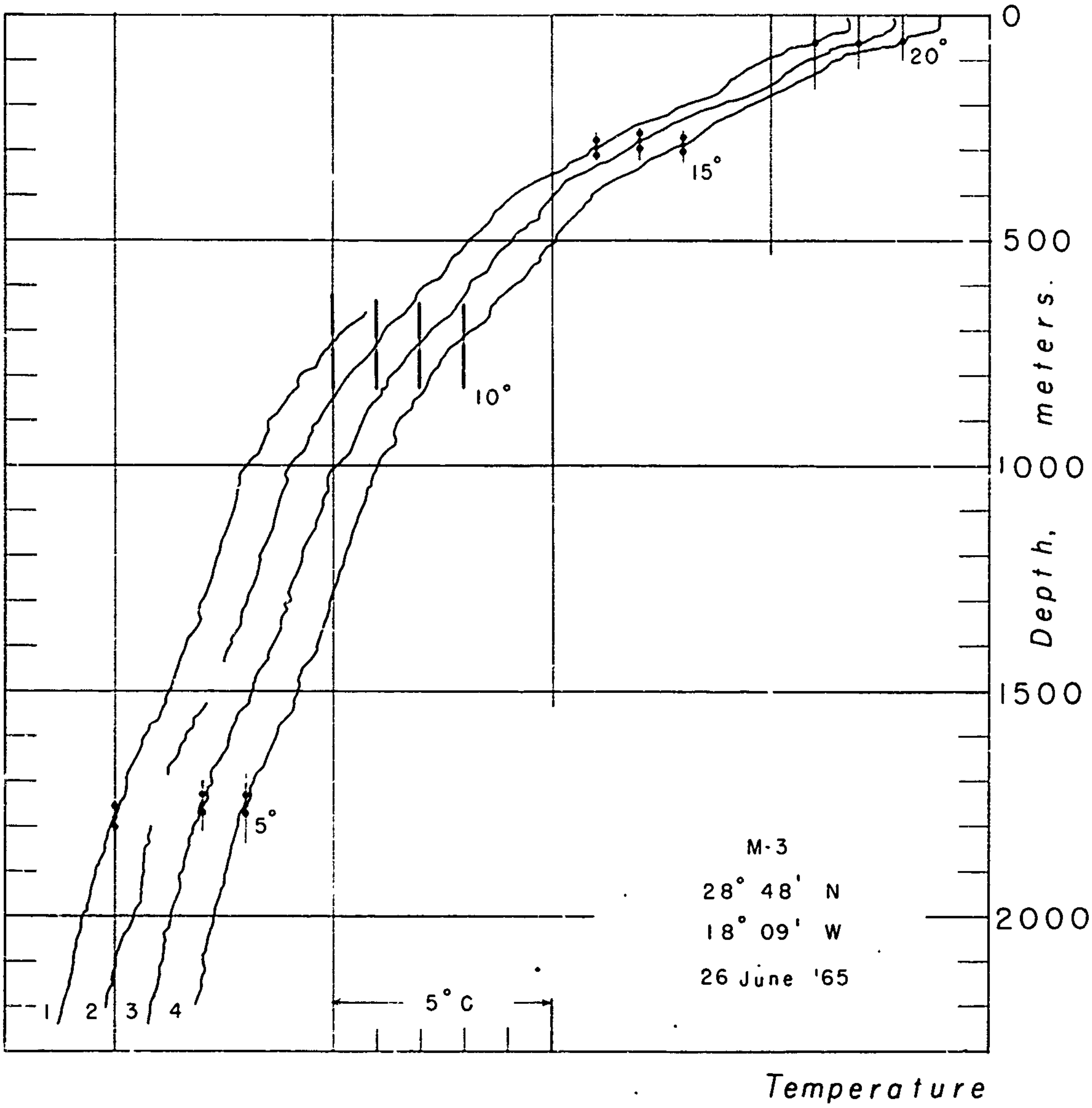


Fig. 6 *Temperatures* - Station M-3

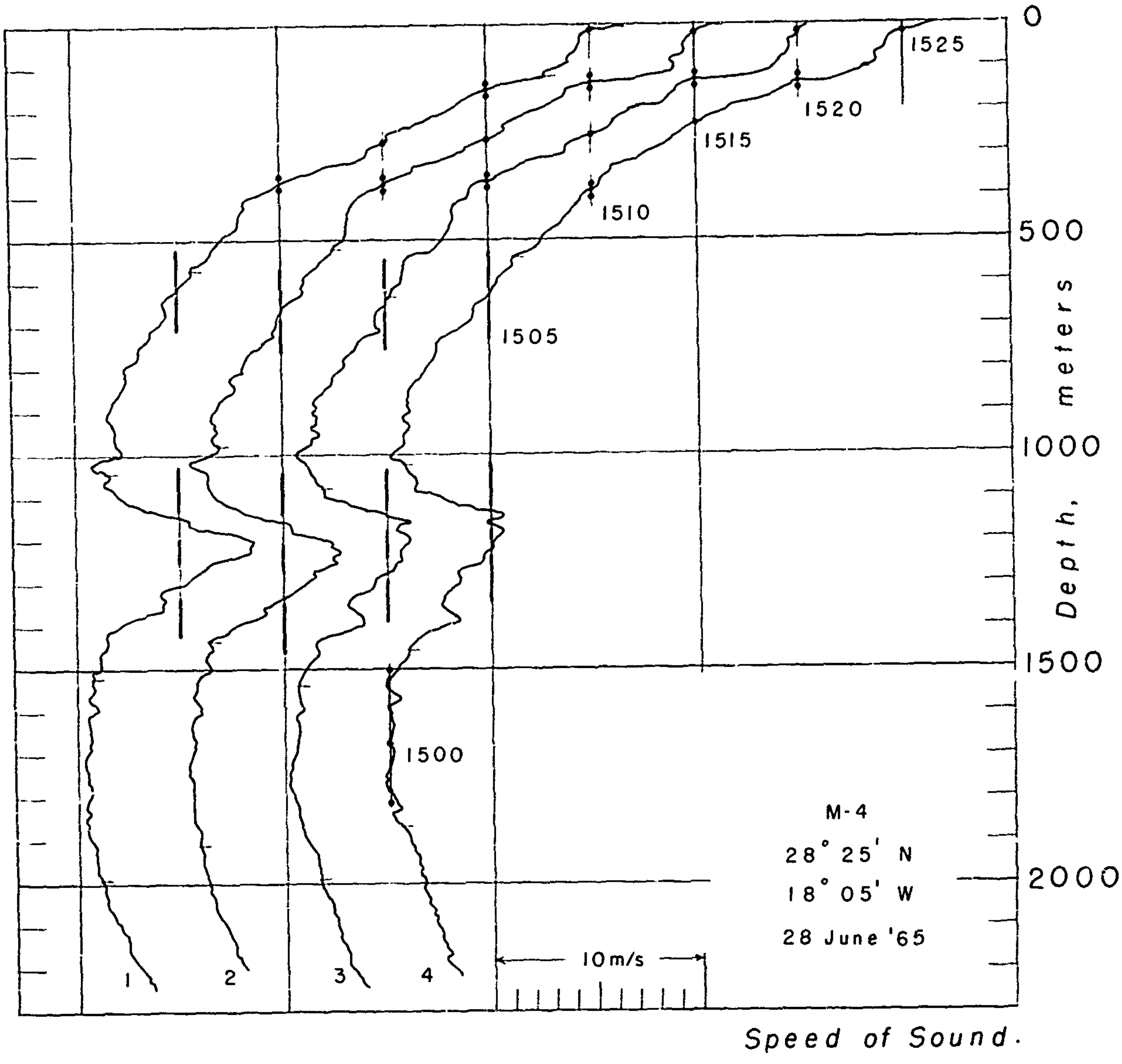


Fig. 7 *Sound Speeds - Station M-4*

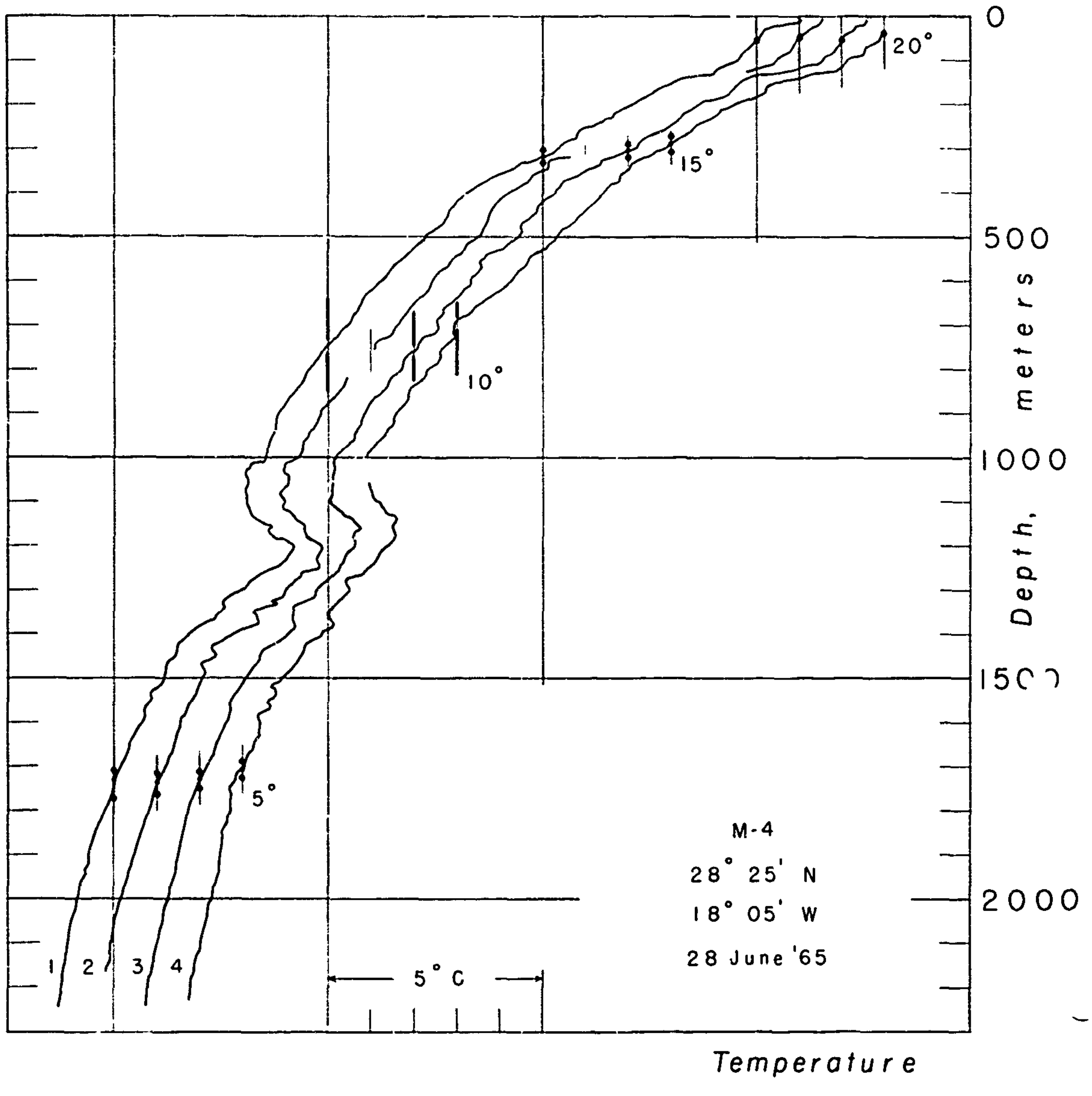


Fig. 8 *Temperatures* - Station M-4

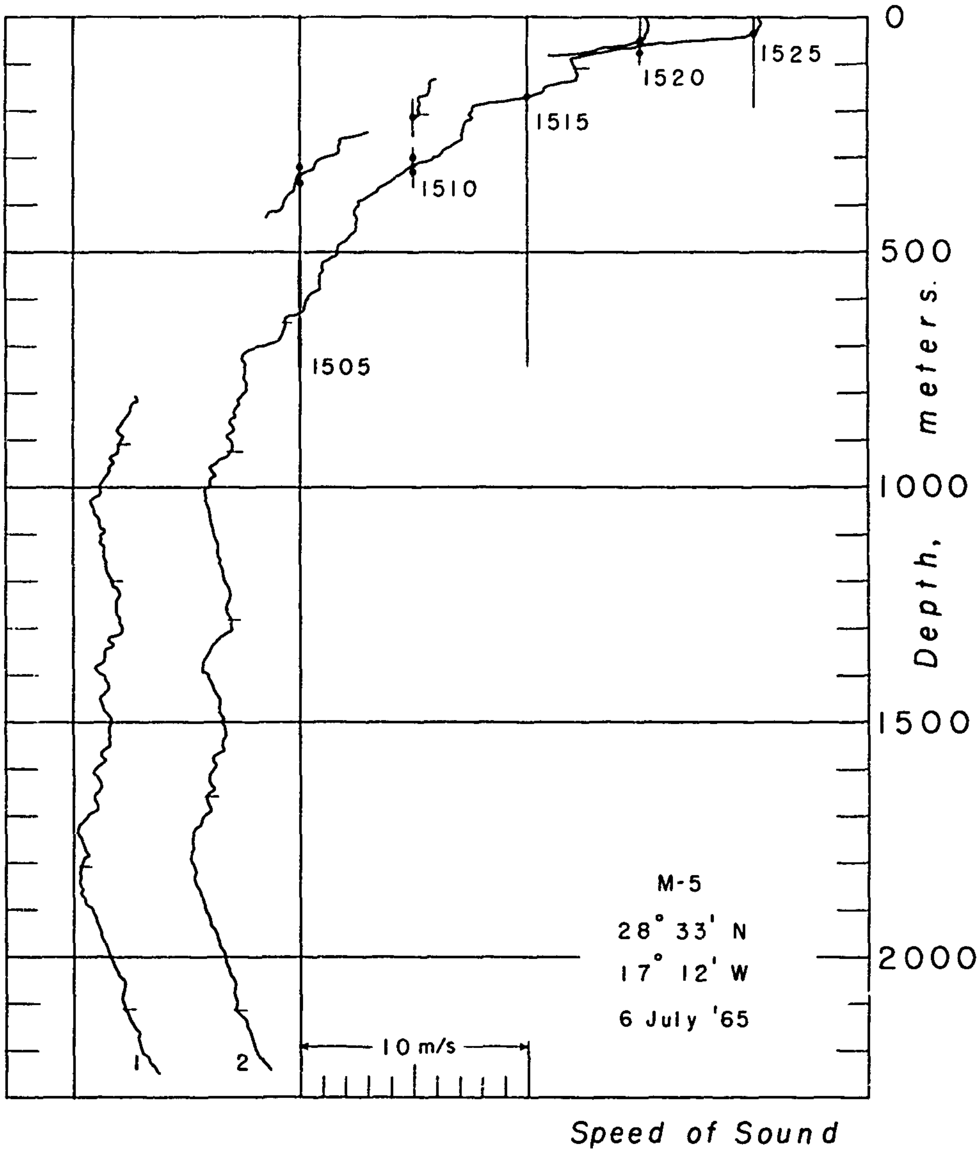


Fig. 9 *Sound Speeds* - Station M-5

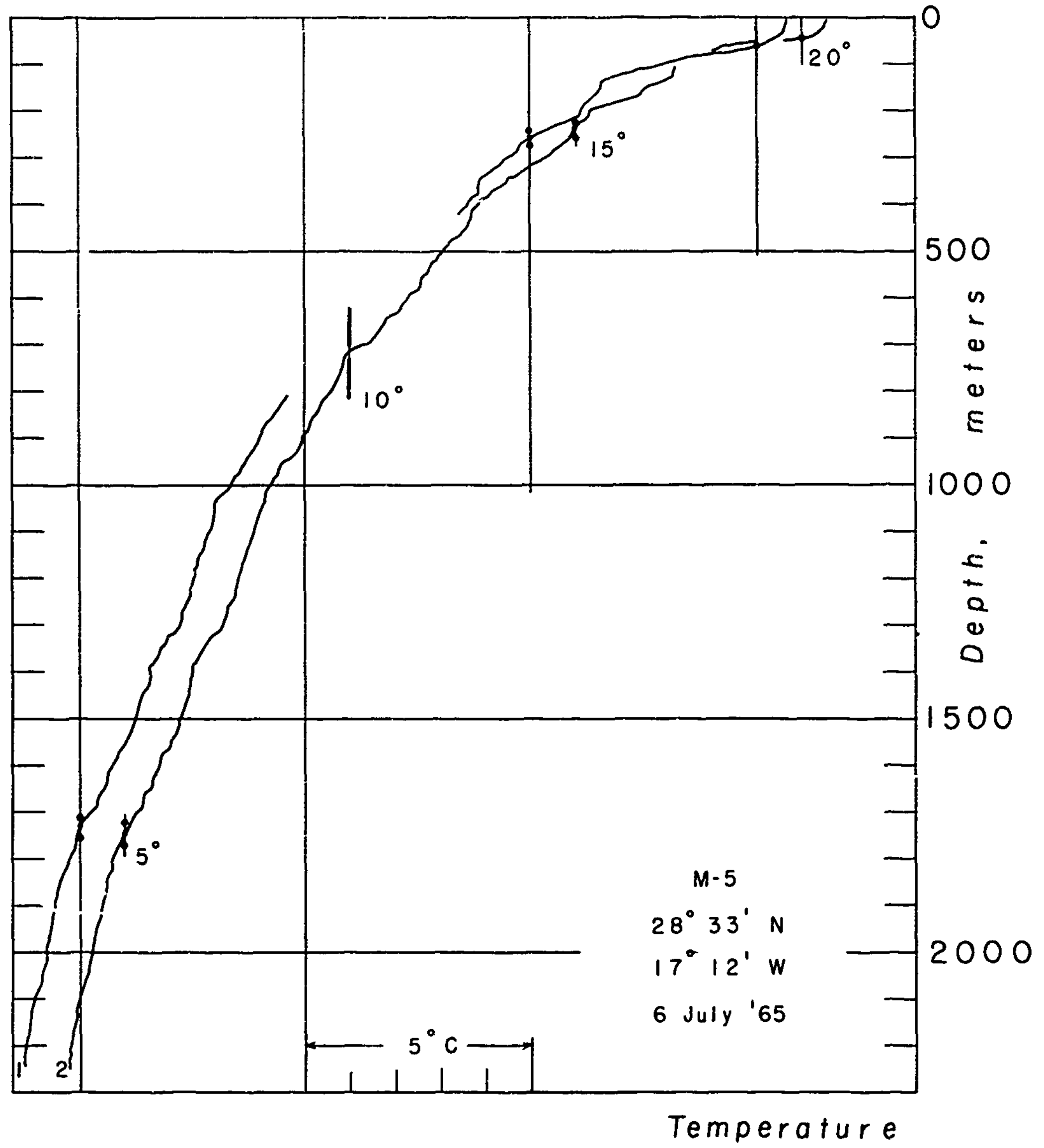


Fig. 10 *Temperatures* - Station M-5

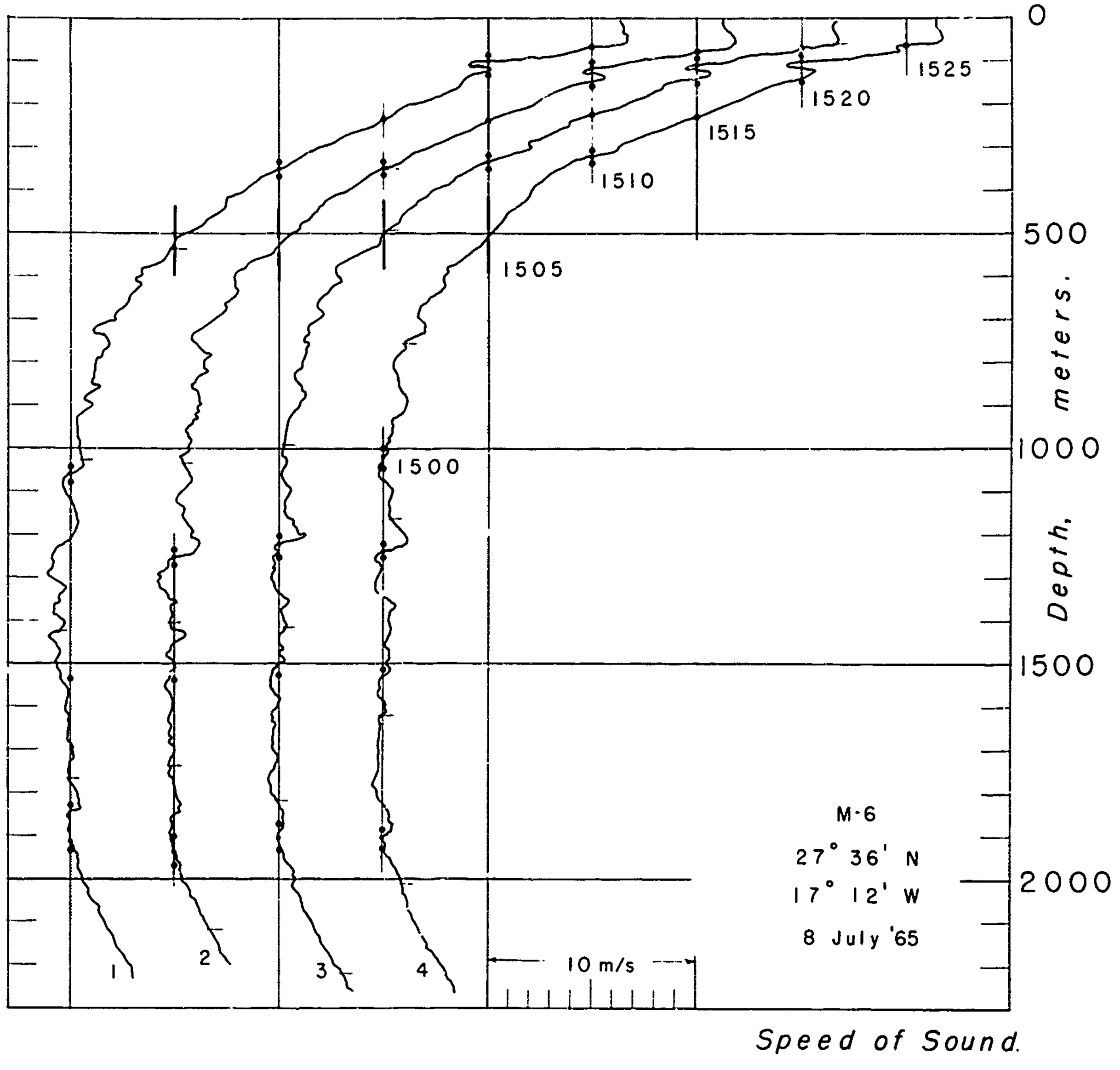


Fig. 11 Sound Speeds - Station M-6

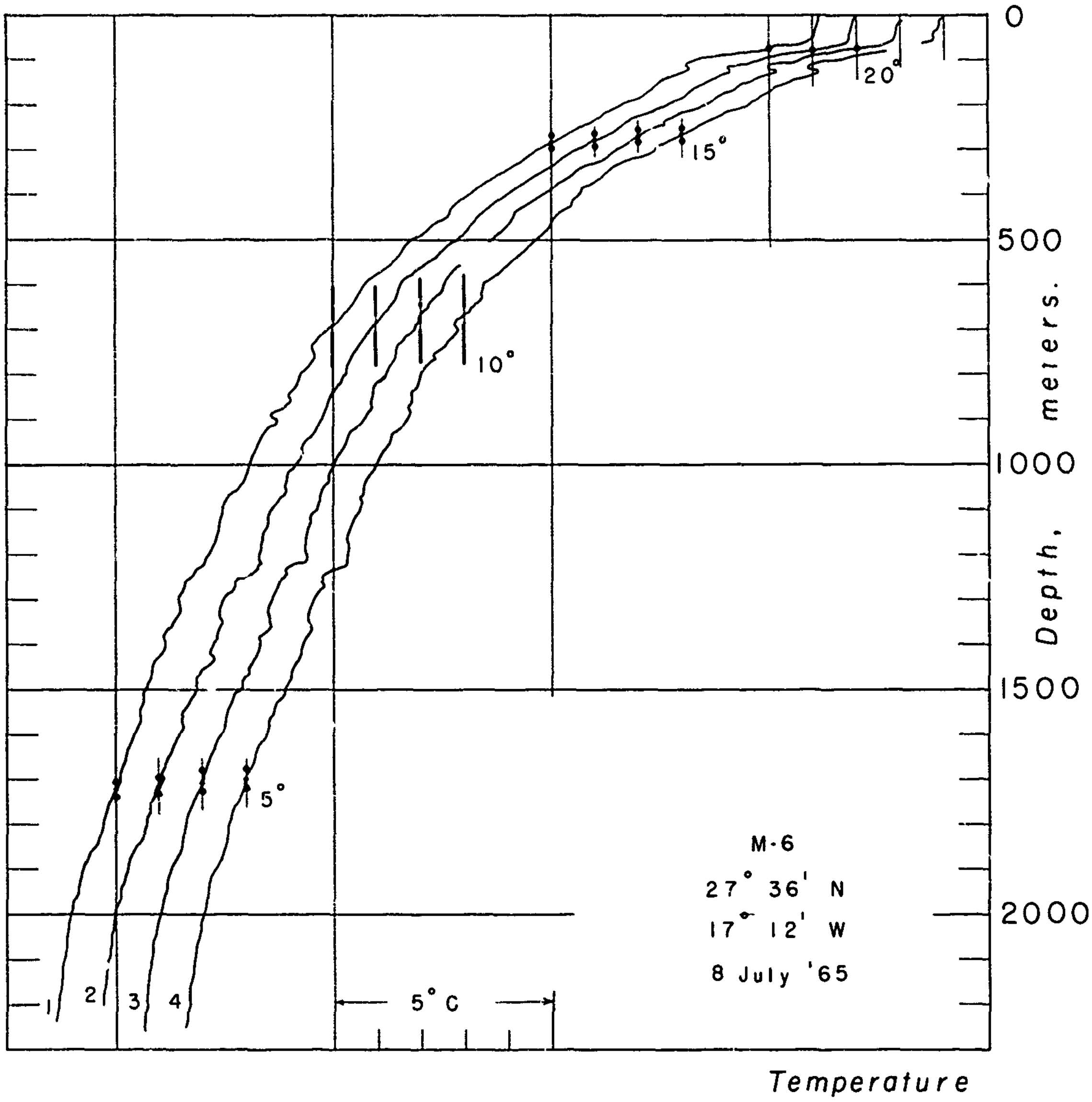


Fig. 12 *Temperatures* - Station M-6

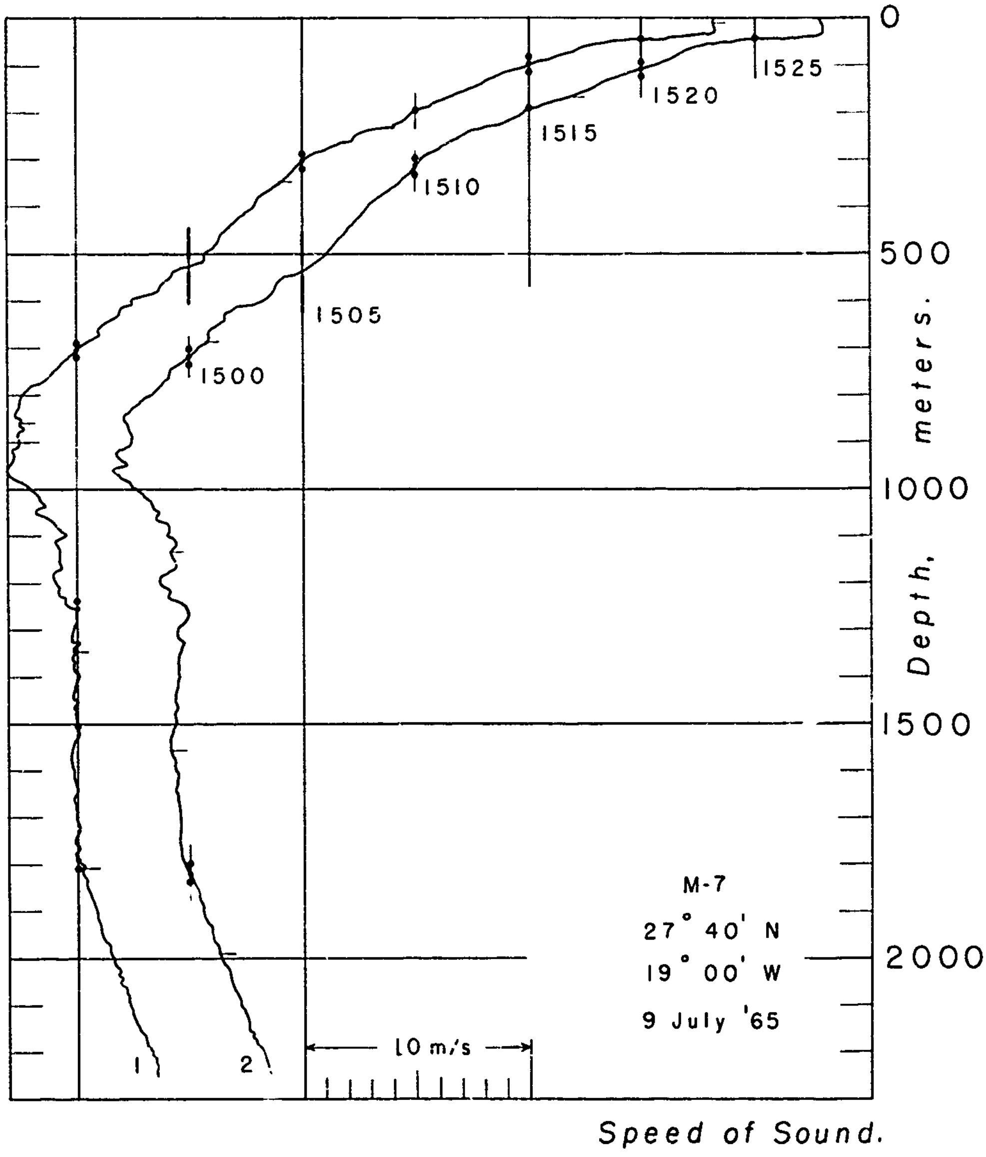


Fig. 13 *Sound Speeds* - Station M - 7

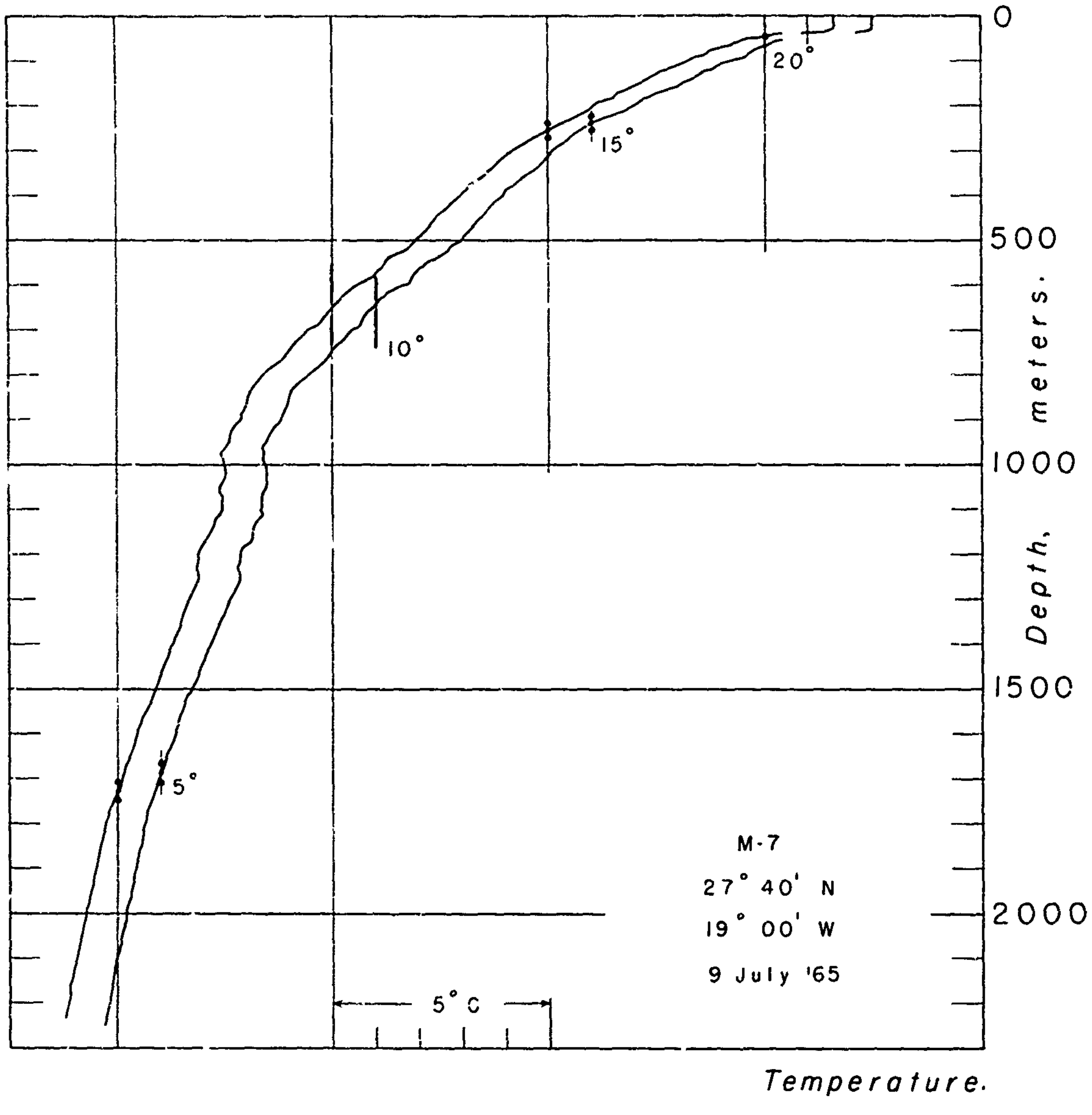


Fig. 14 *Temperatures* - Station M-7

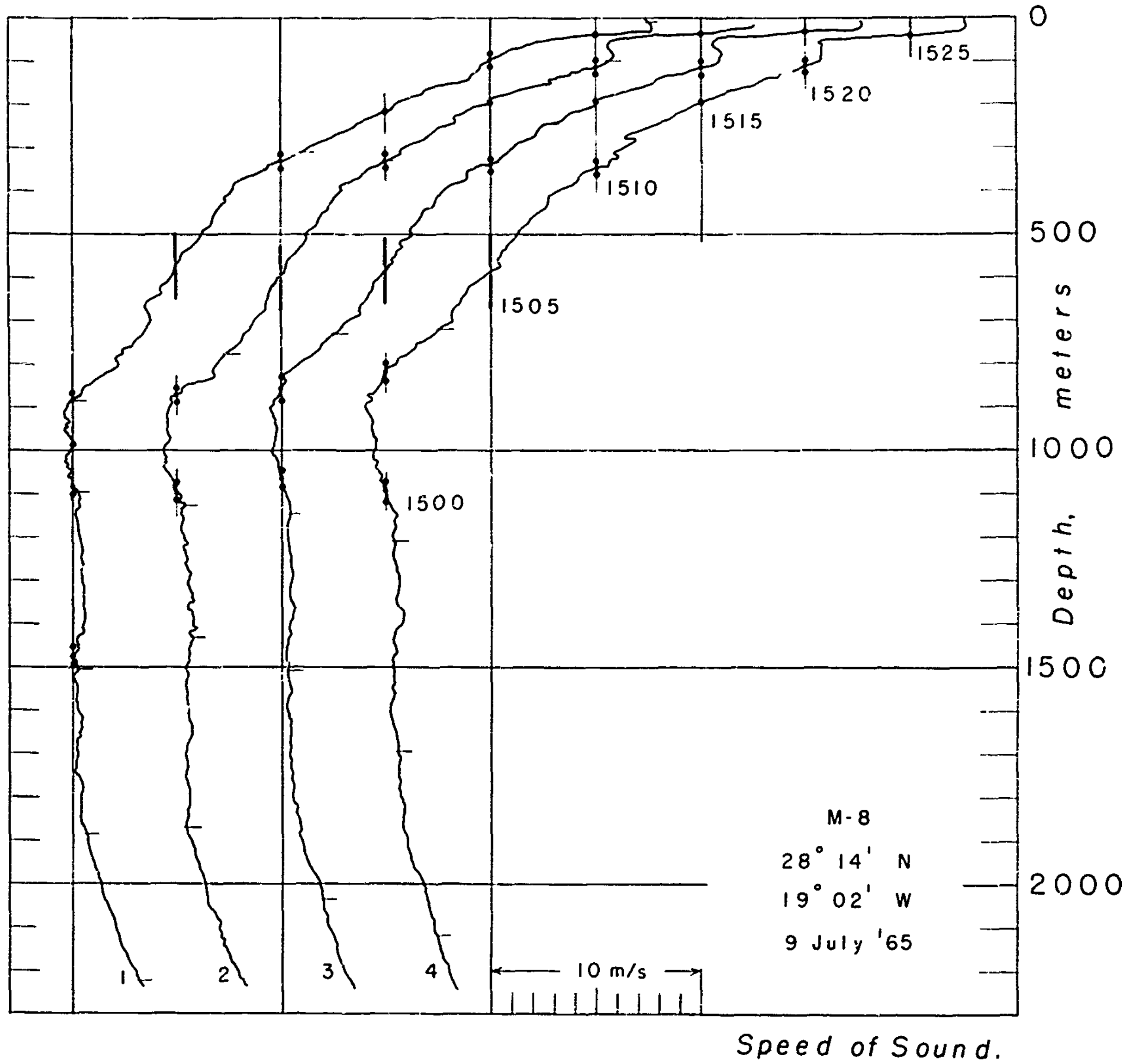


Fig. 15 *Sound Speeds* - Station M-8

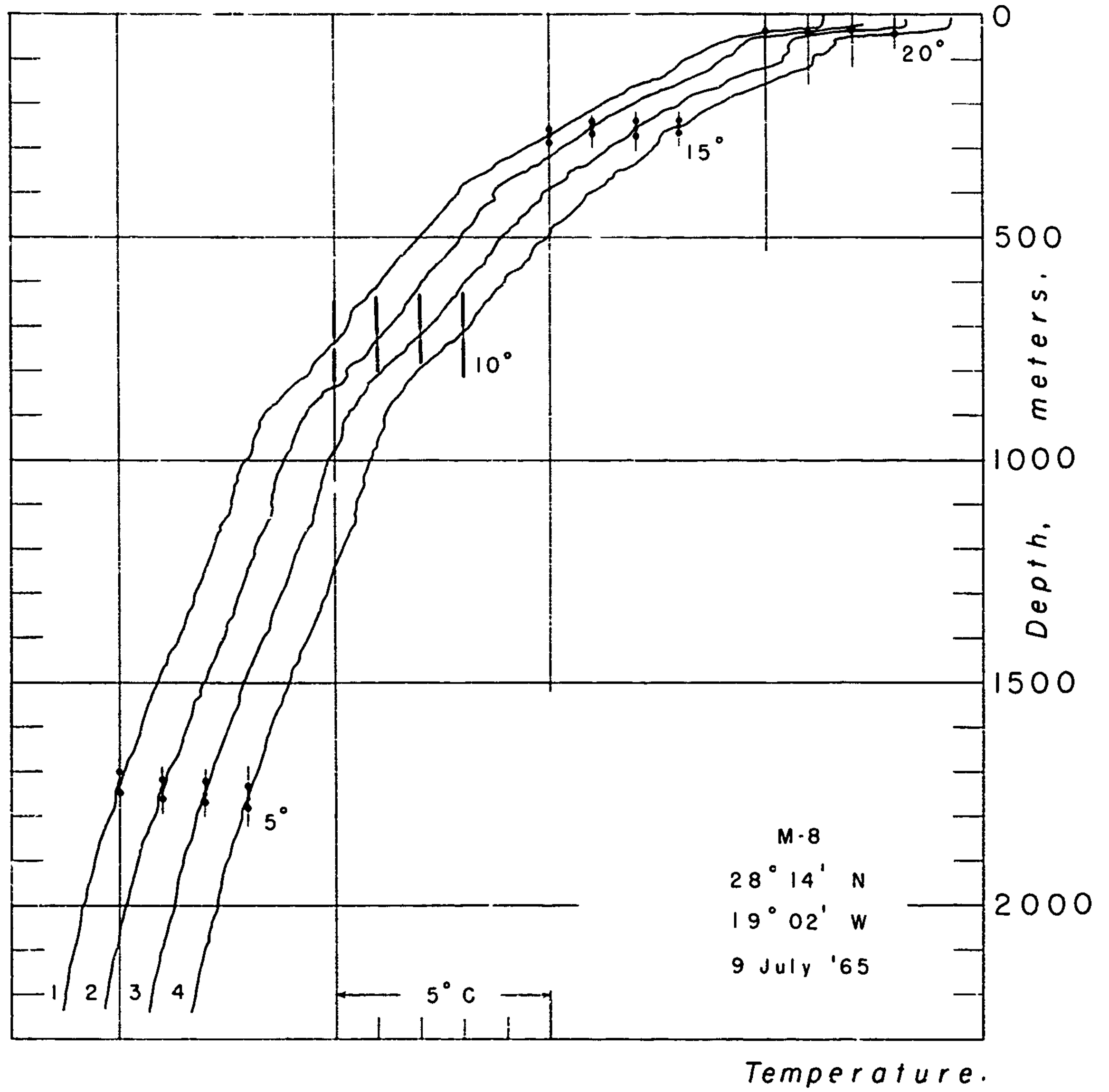


Fig. 16 *Temperatures* - Station M-8

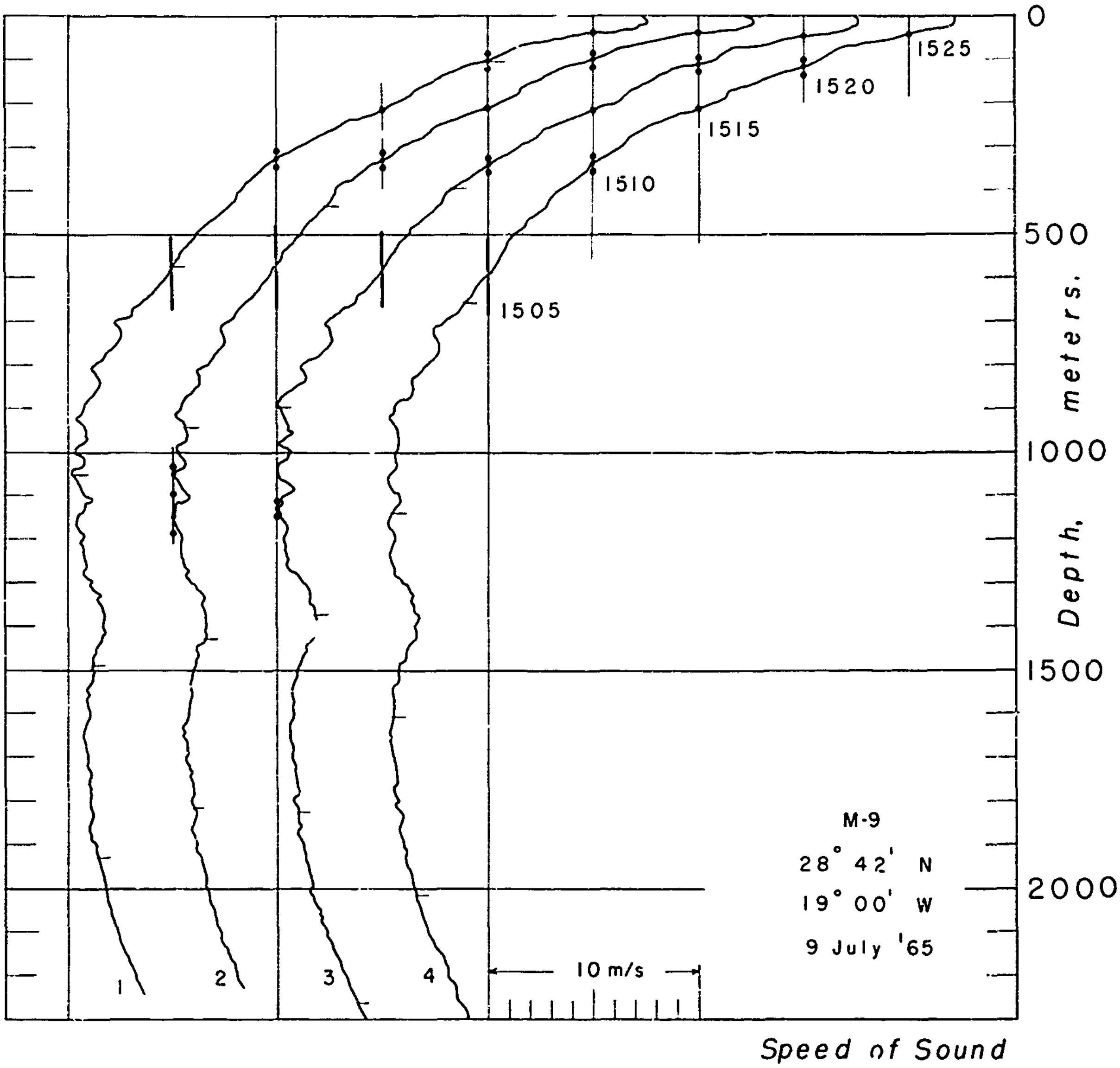


Fig. 17 Sound Speeds - Station M-9

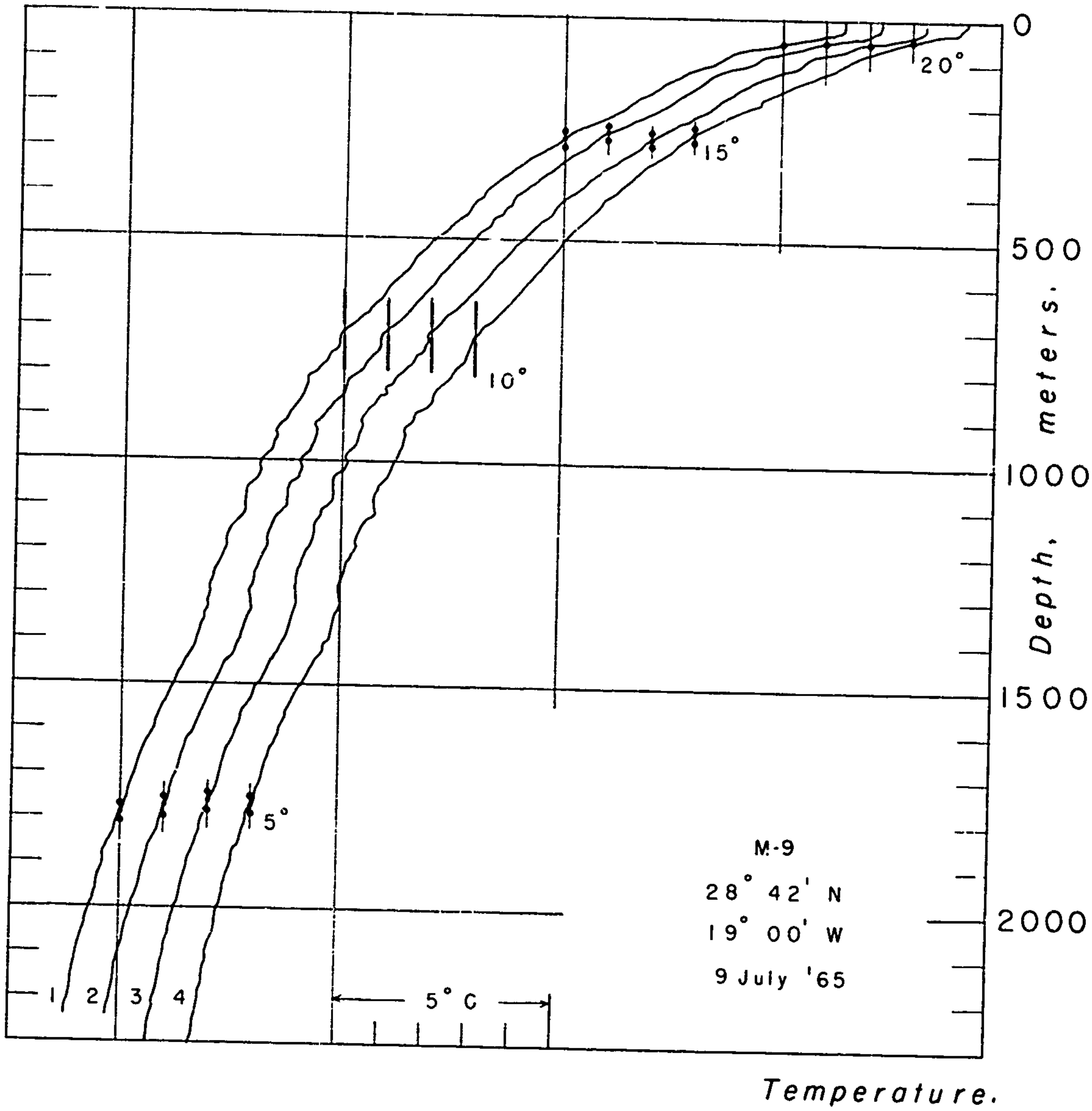


Fig. 18 *Temperatures* - Station M-9

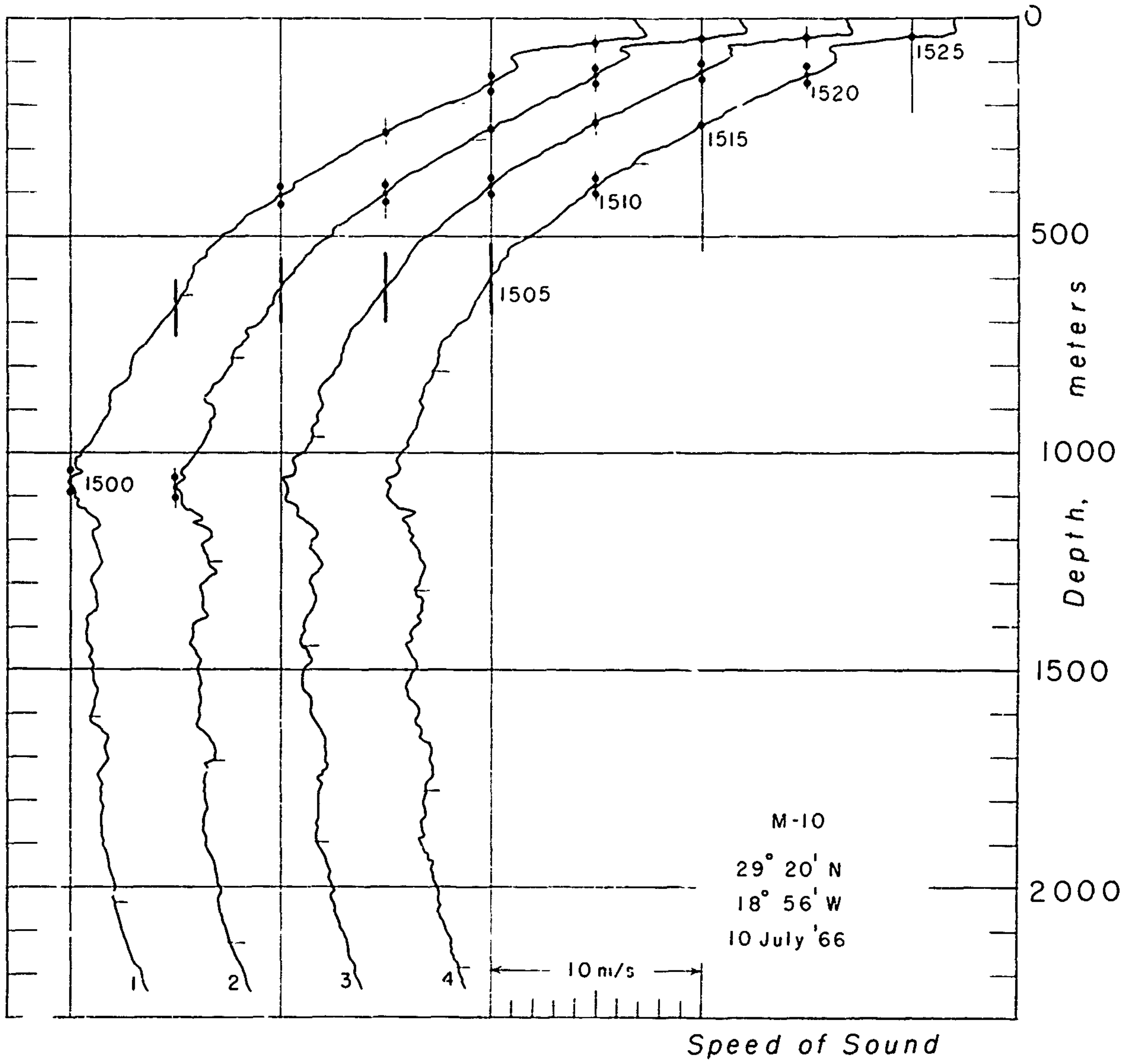


Fig. 19 *Sound Speeds* - Station M-10

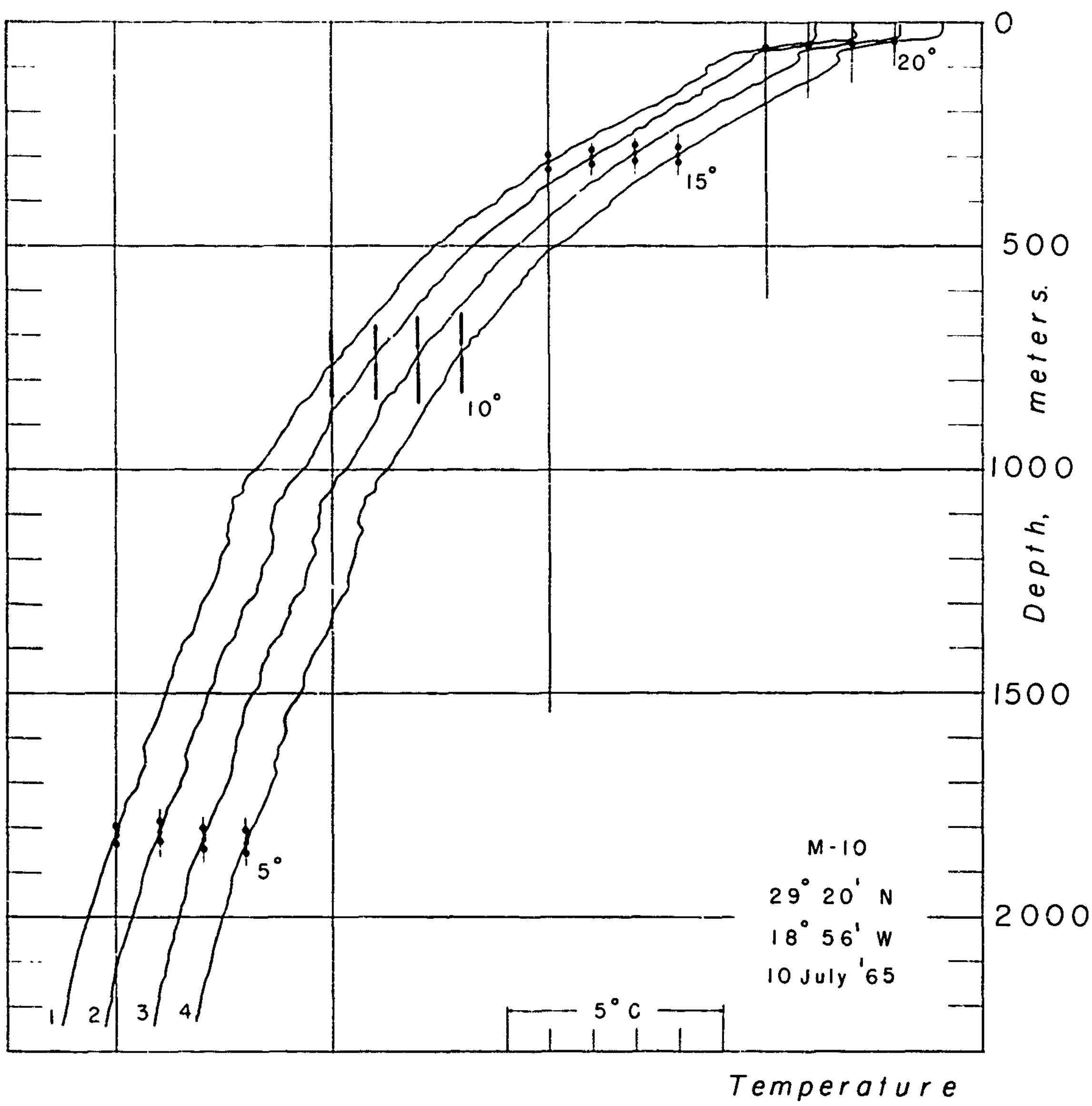


Fig. 20 *Temperatures* - Station M-10

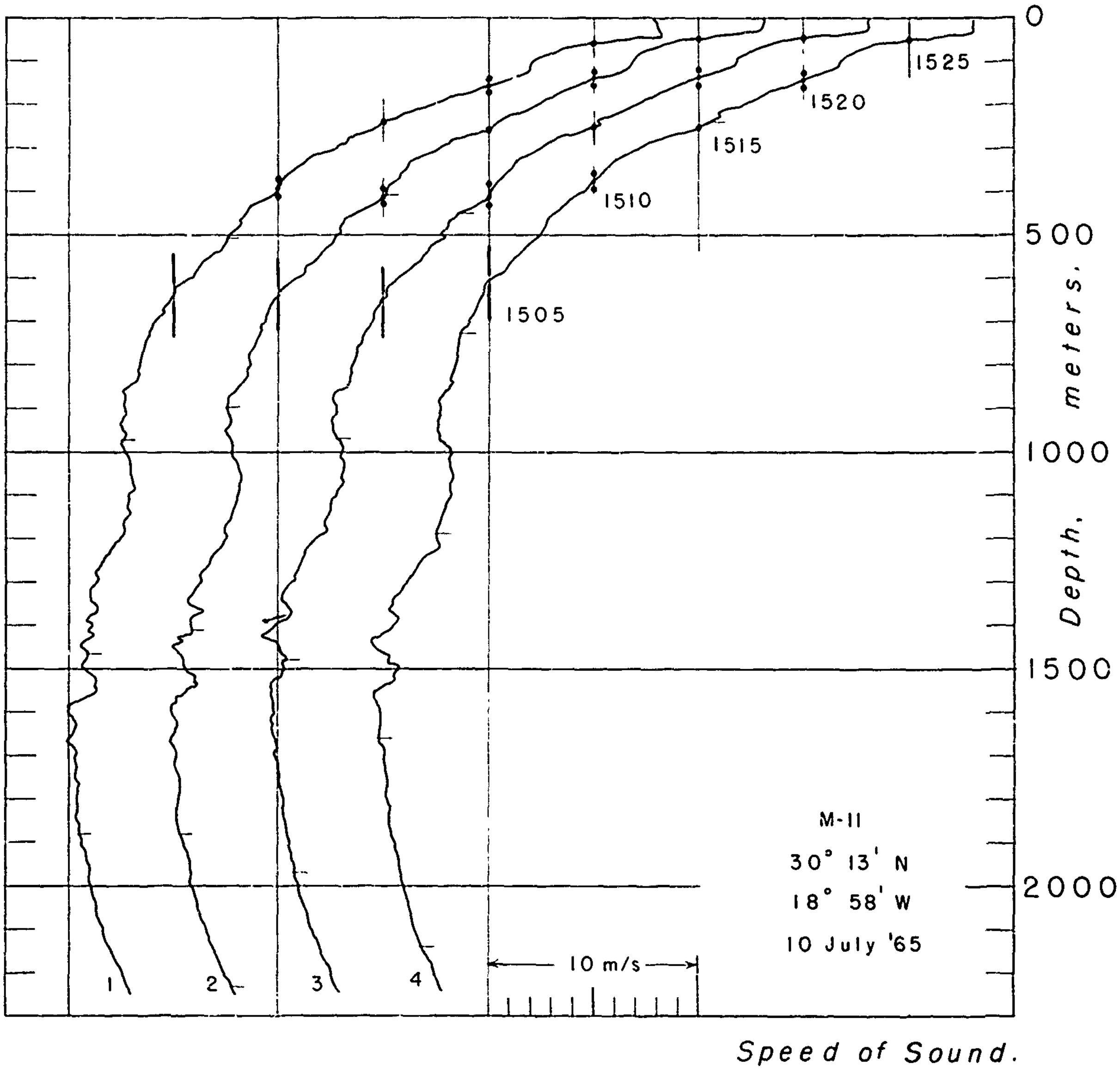


Fig. 21 Sound Speeds - Station M-11

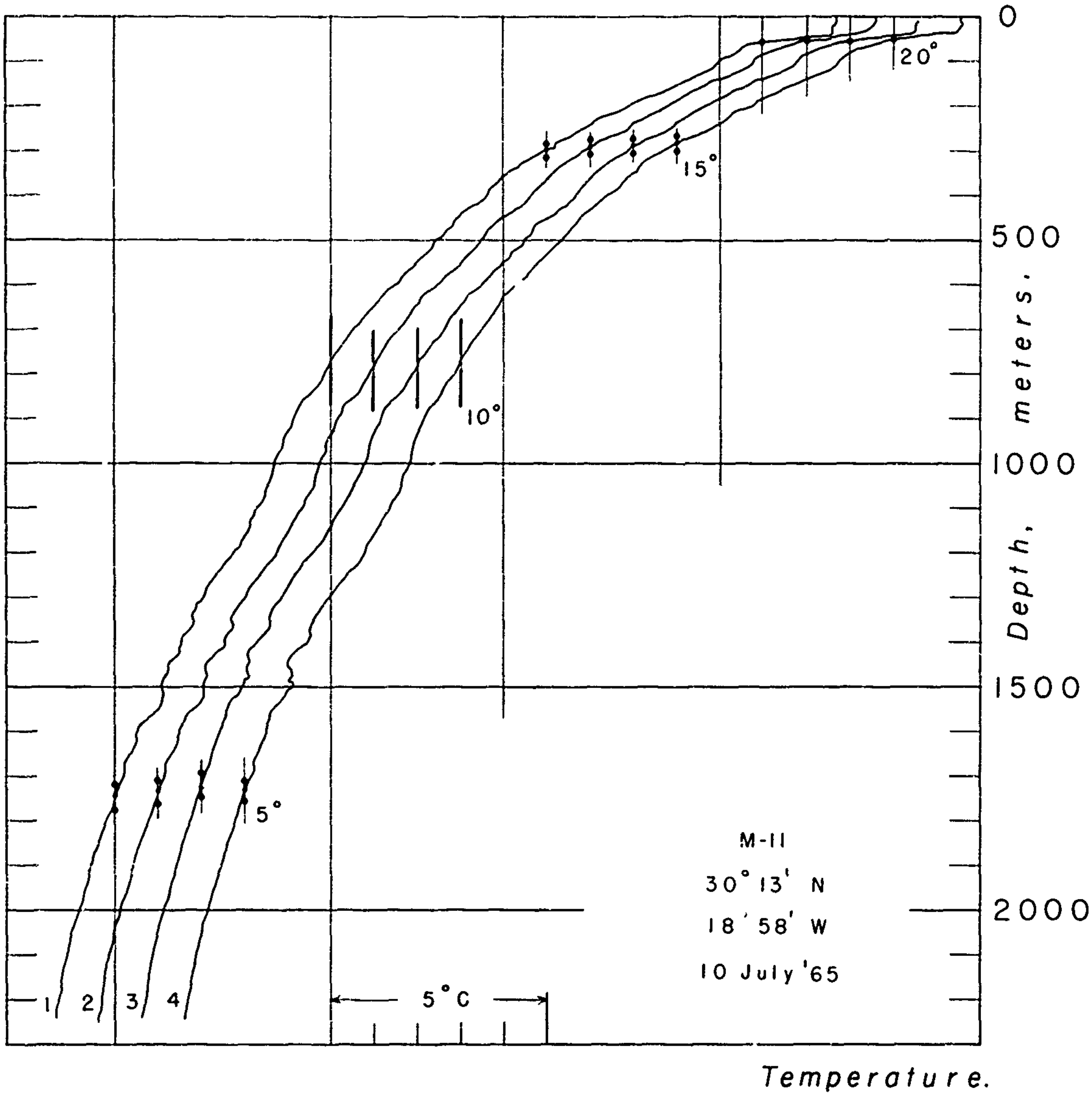


Fig. 22 *Temperatures* - Station M-11

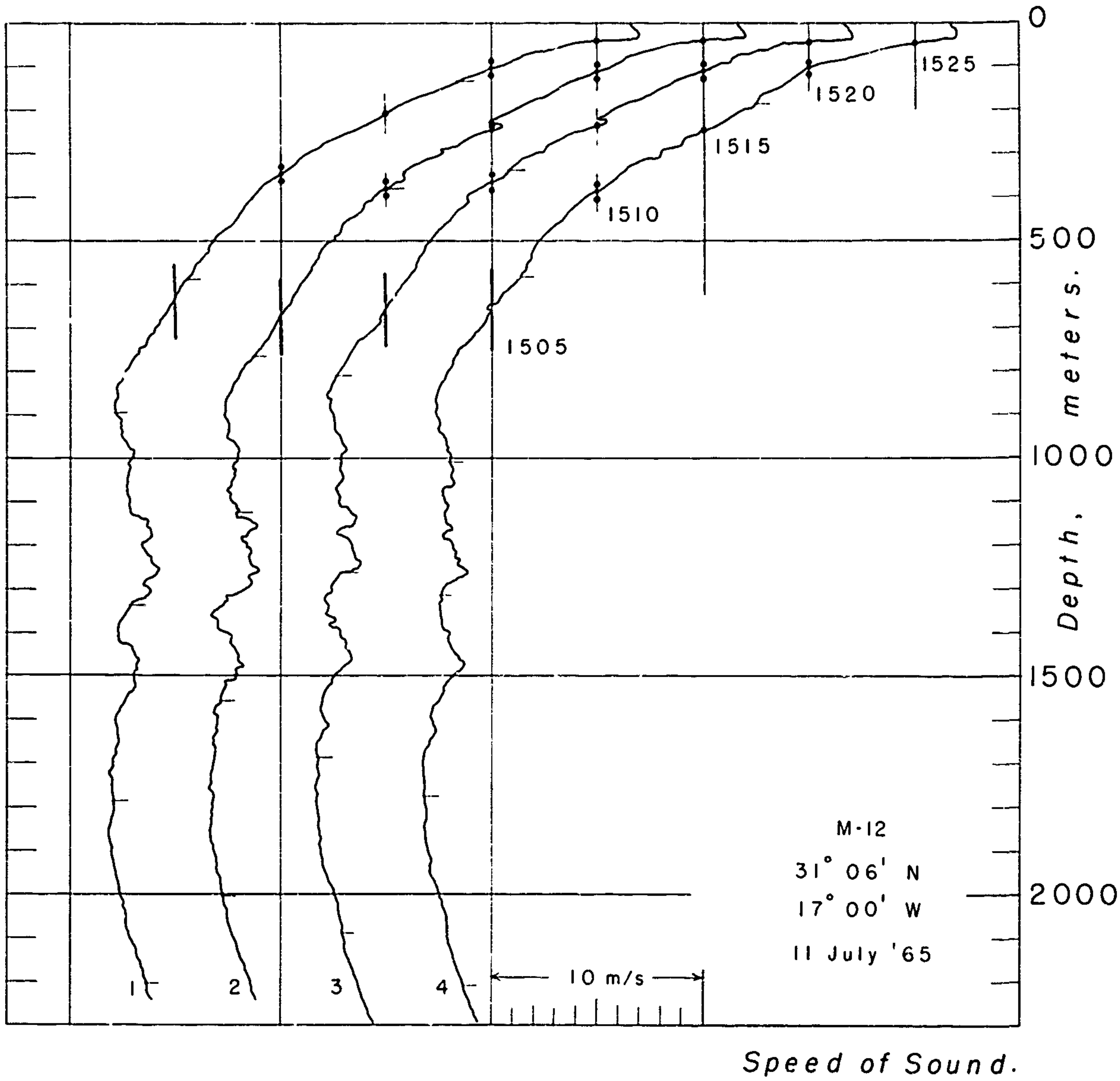


Fig. 23 *Sound Speeds* - Station M-12

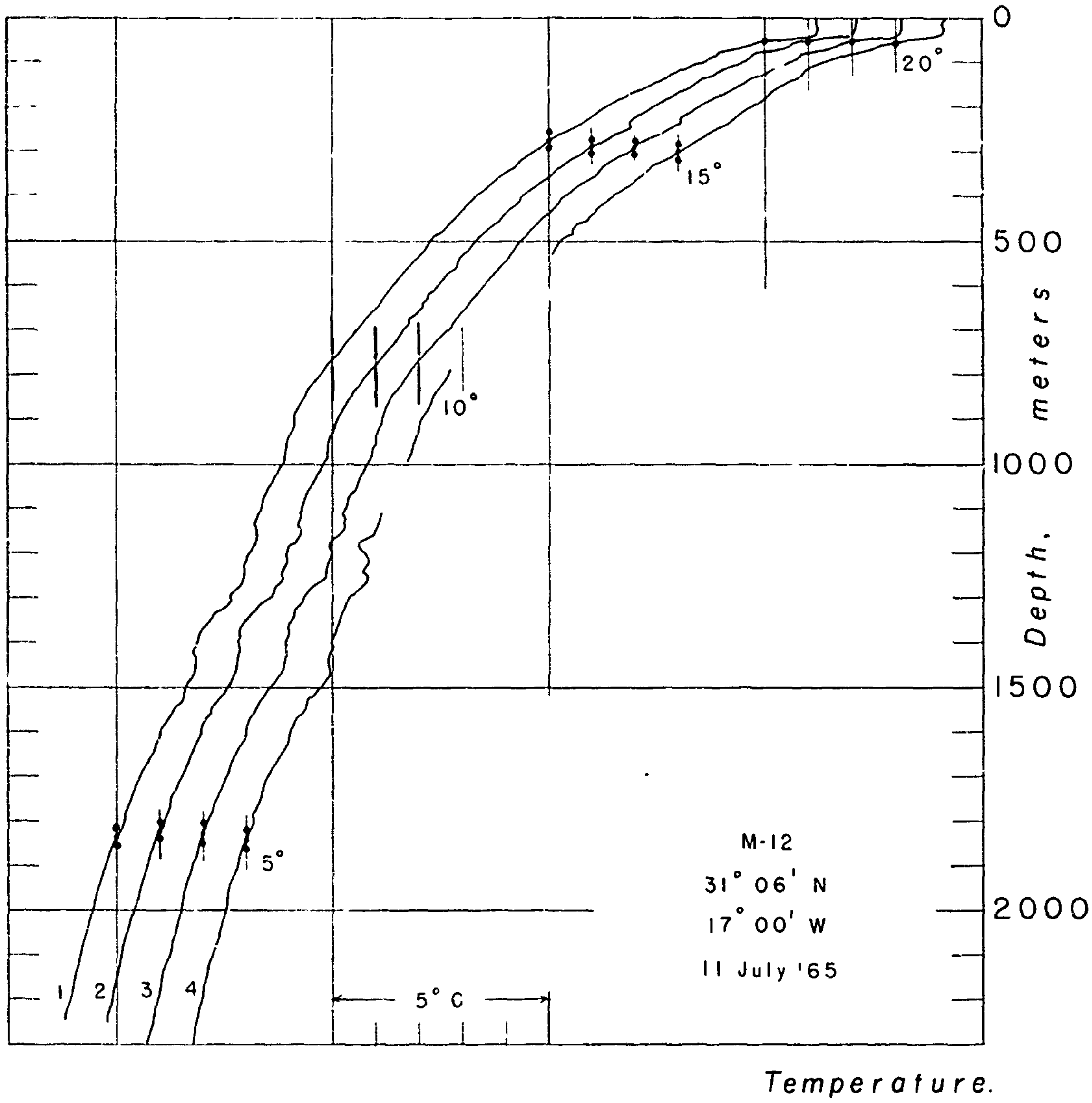


Fig. 24 *Temperatures* - Station M-12

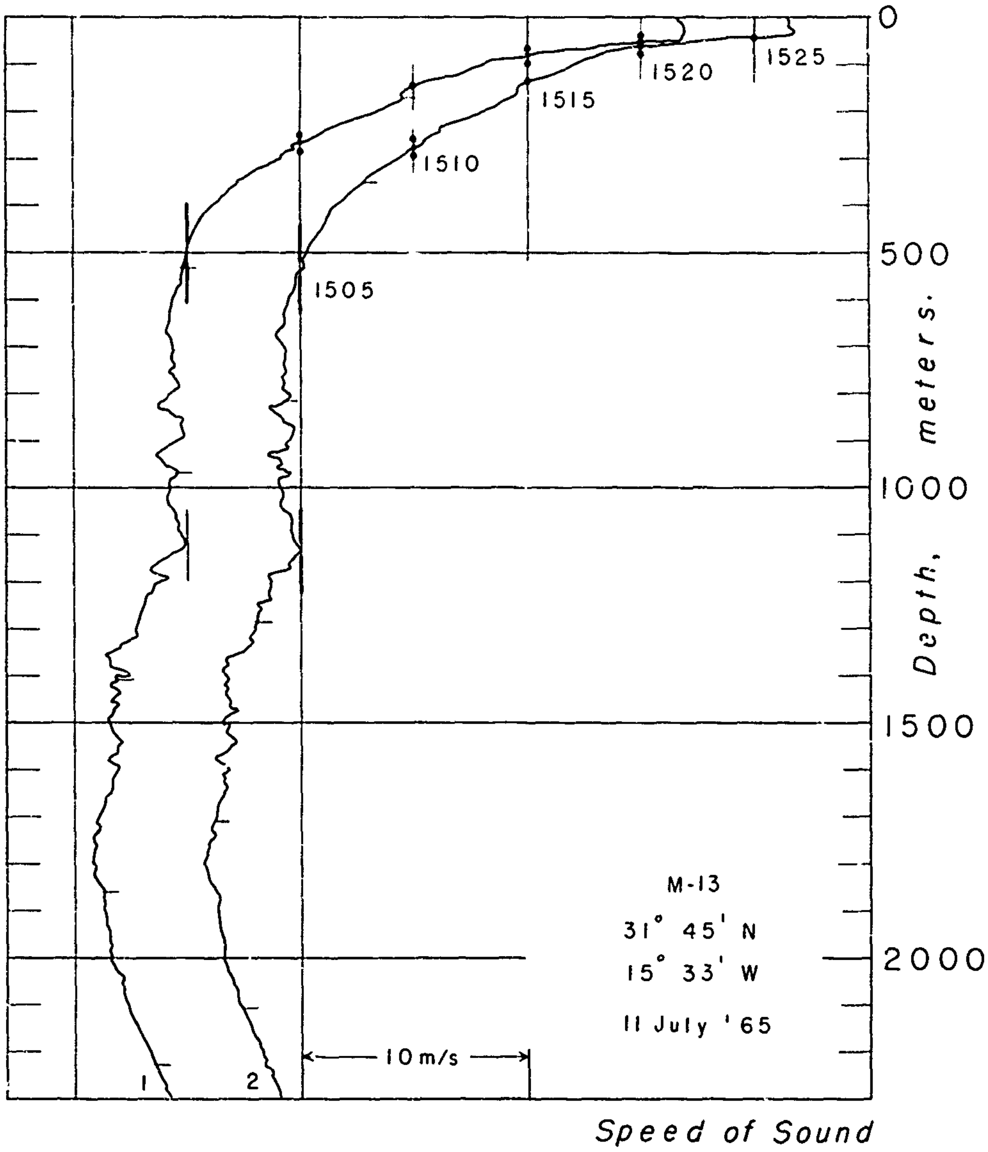
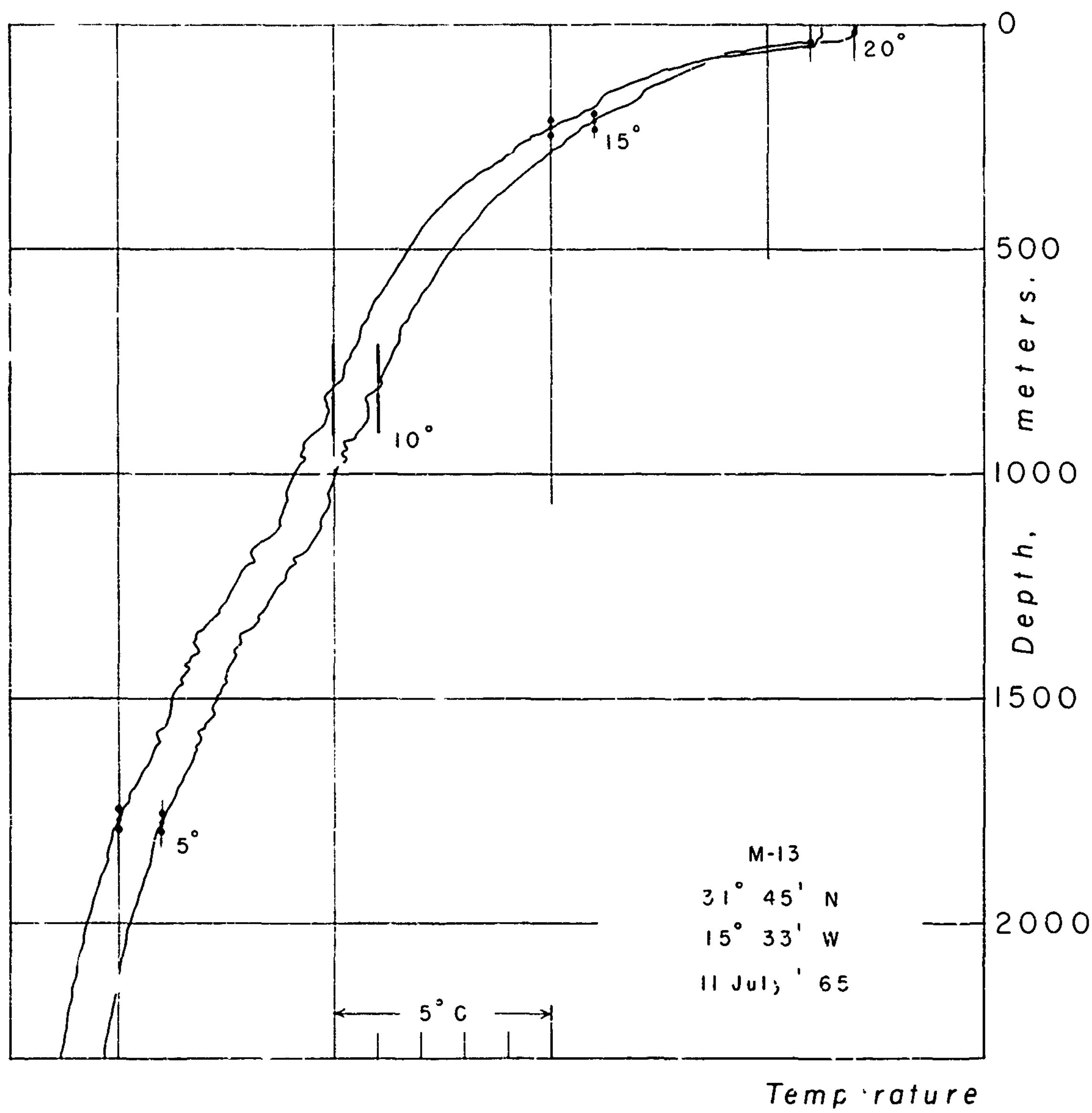


Fig. 25 *Sound Speeds* - Station M-13



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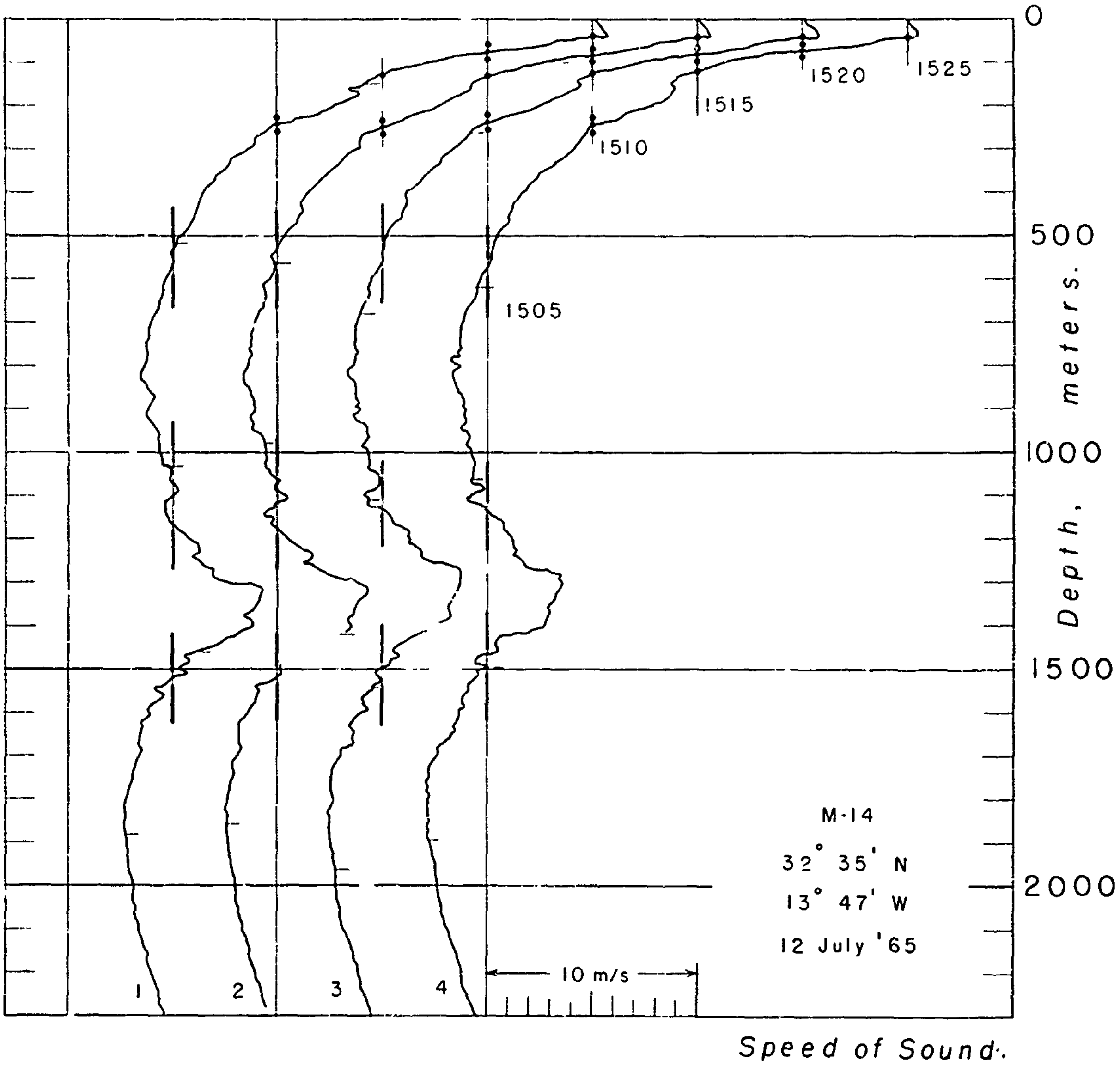

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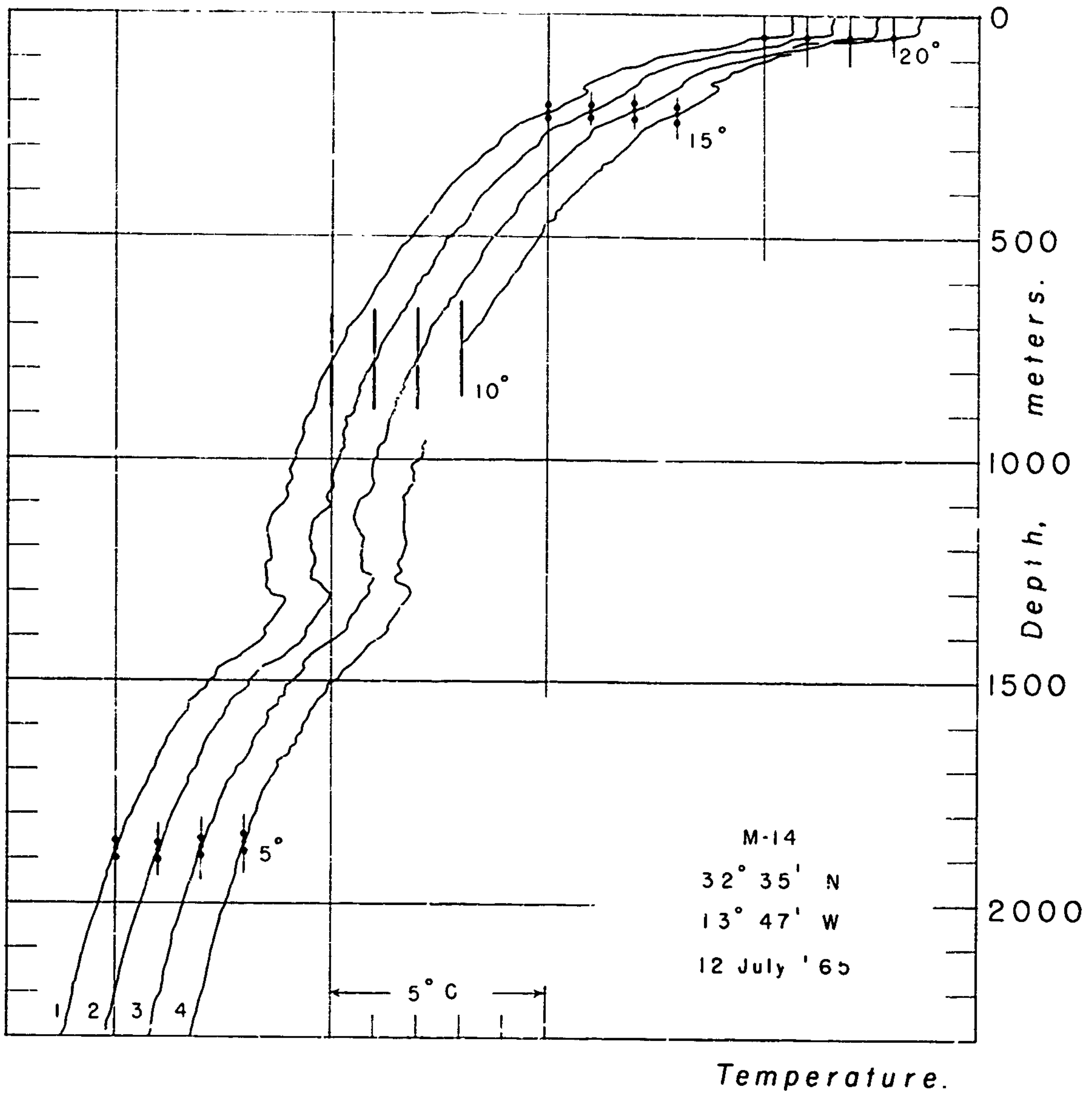

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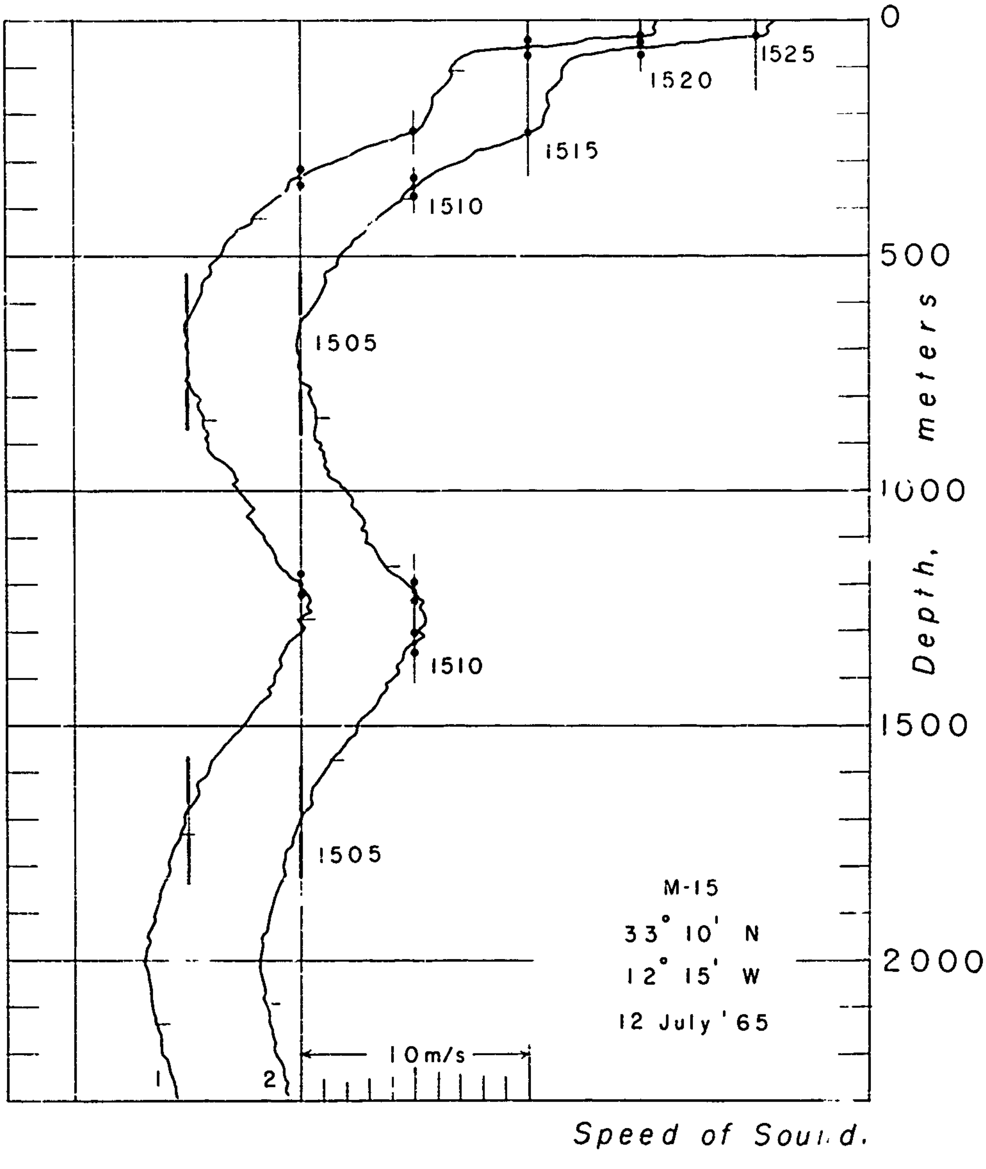

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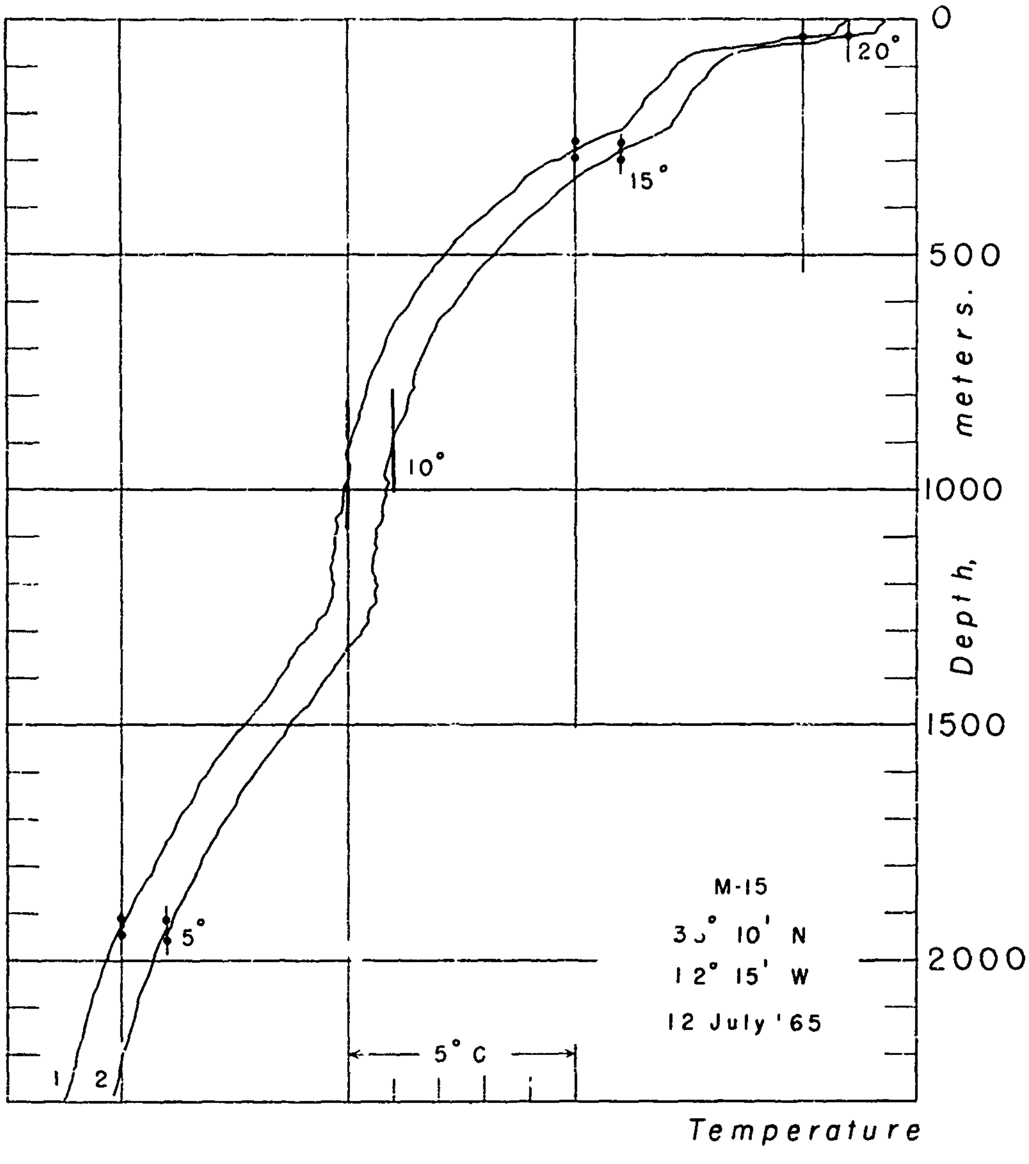
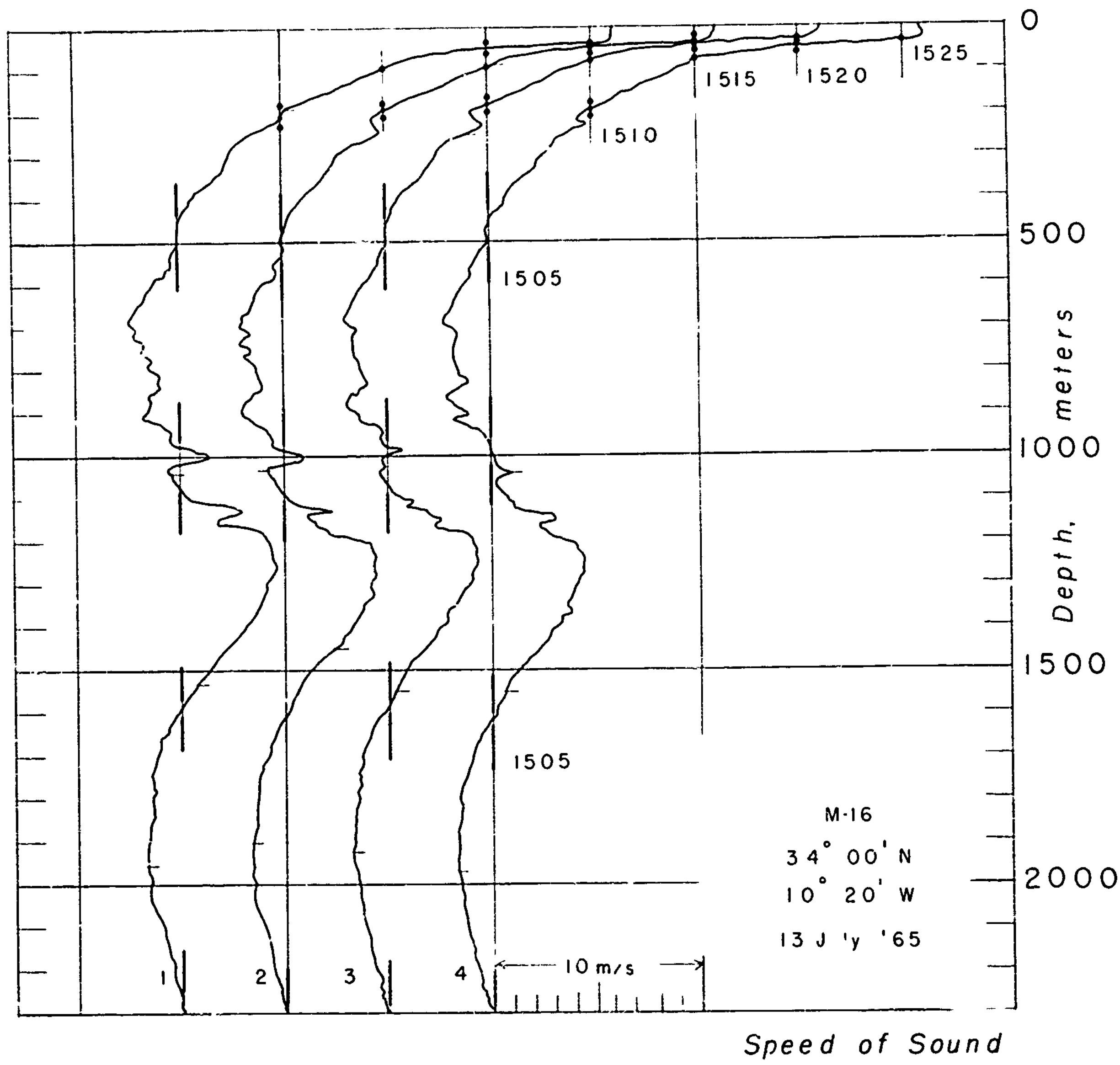


Fig. 30 Temperatures - Station M-15



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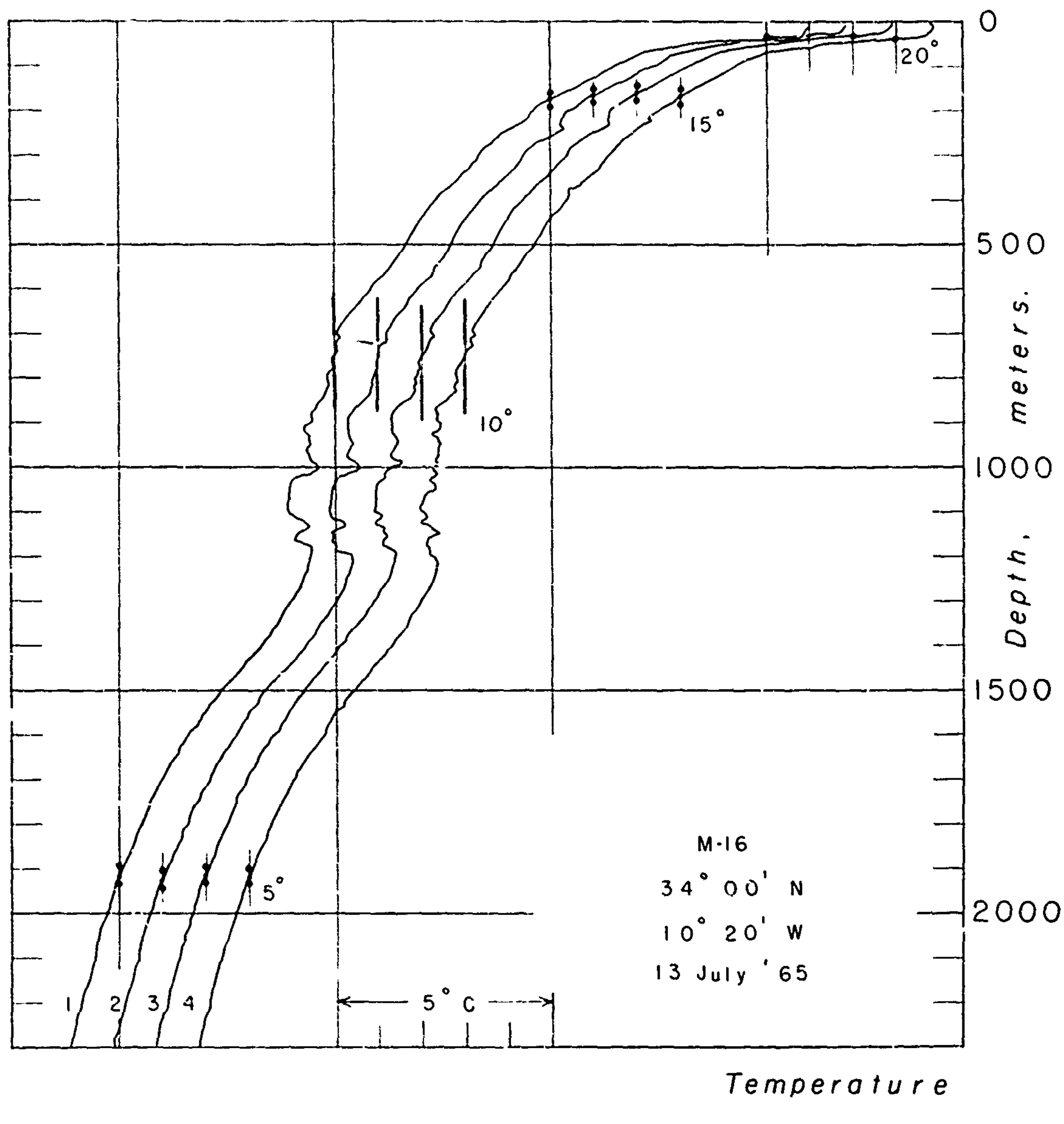


Fig. 32 Temperatures - Station M -16

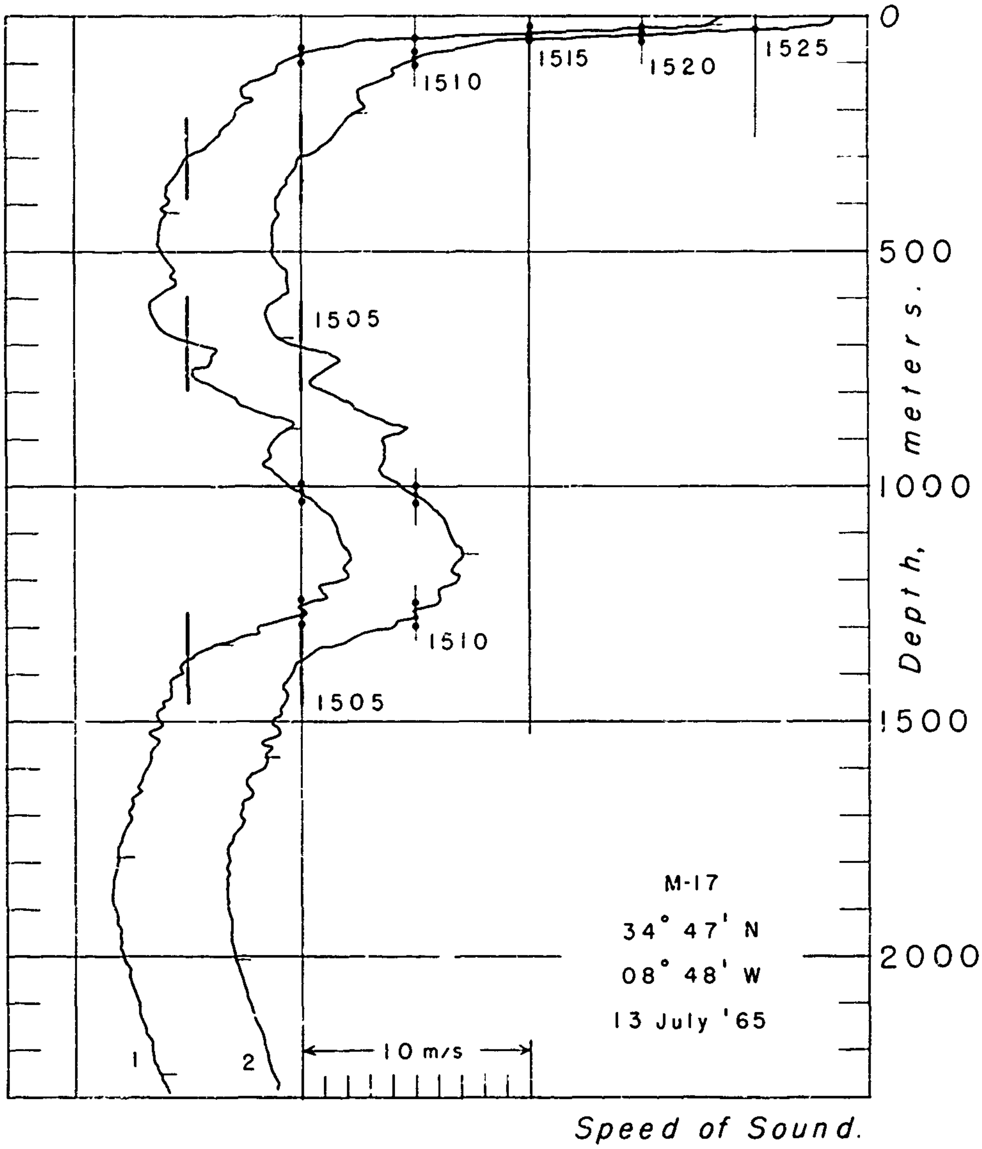


Fig. 33 *Sound Speeds* - Station M - 17

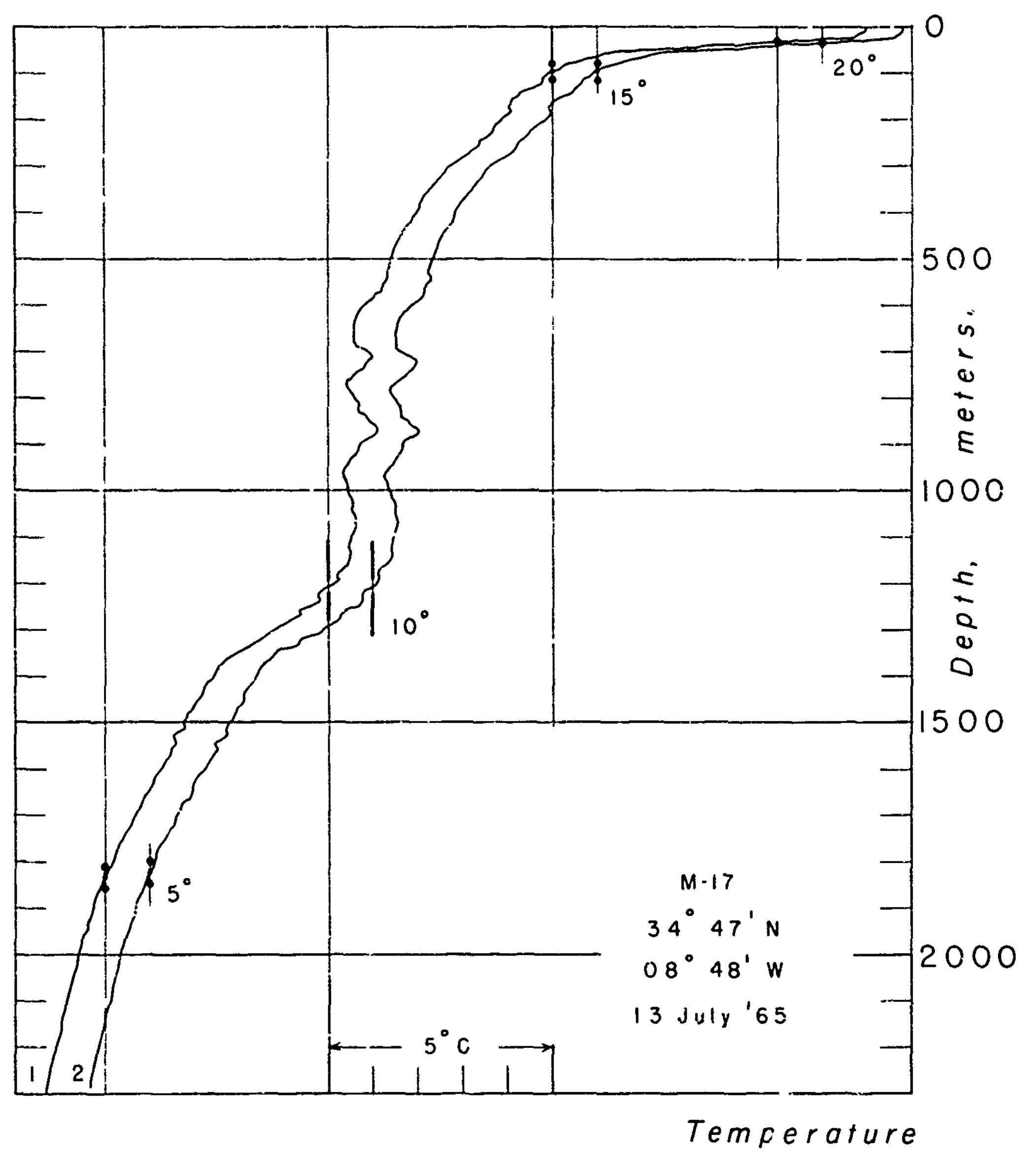
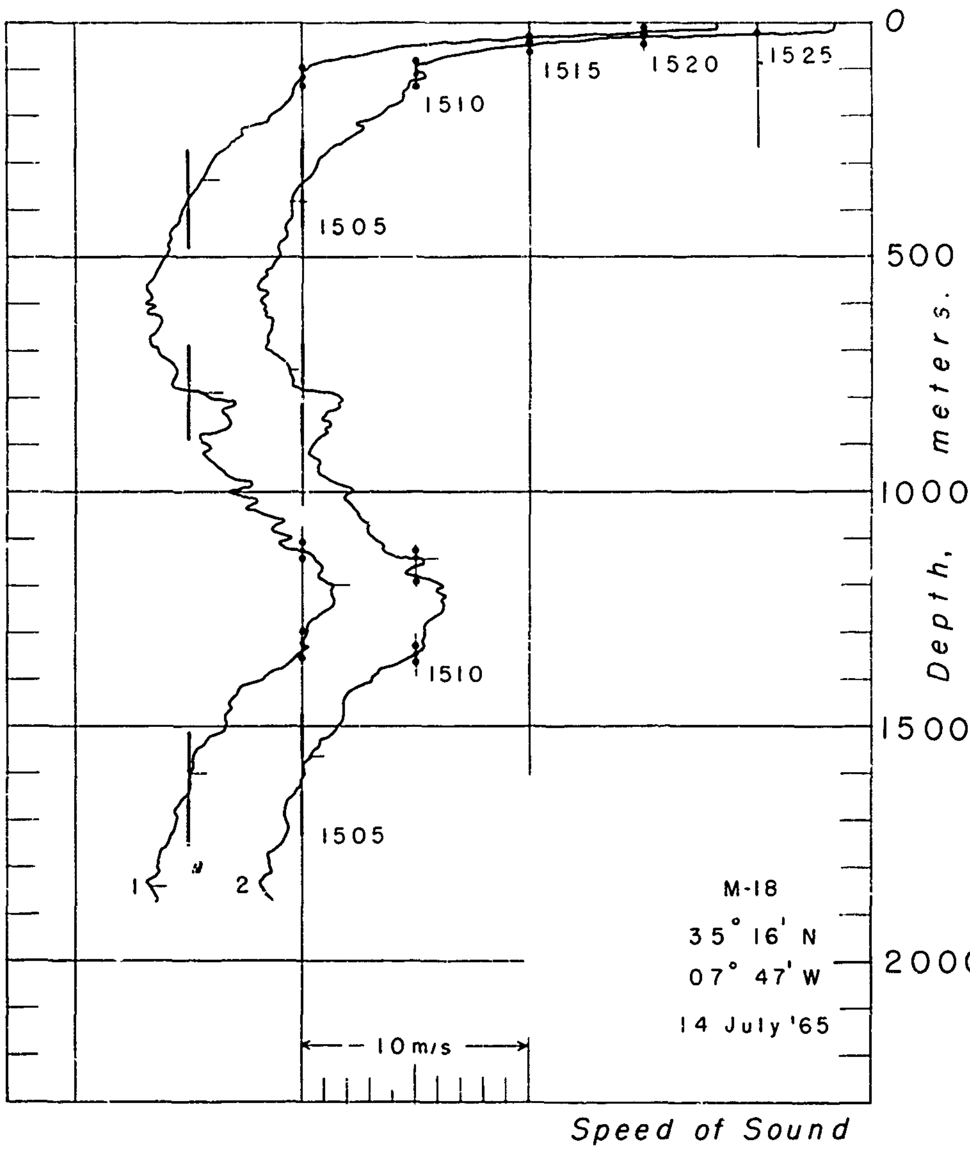


Fig. 3 4 Temperatures - Station M -17



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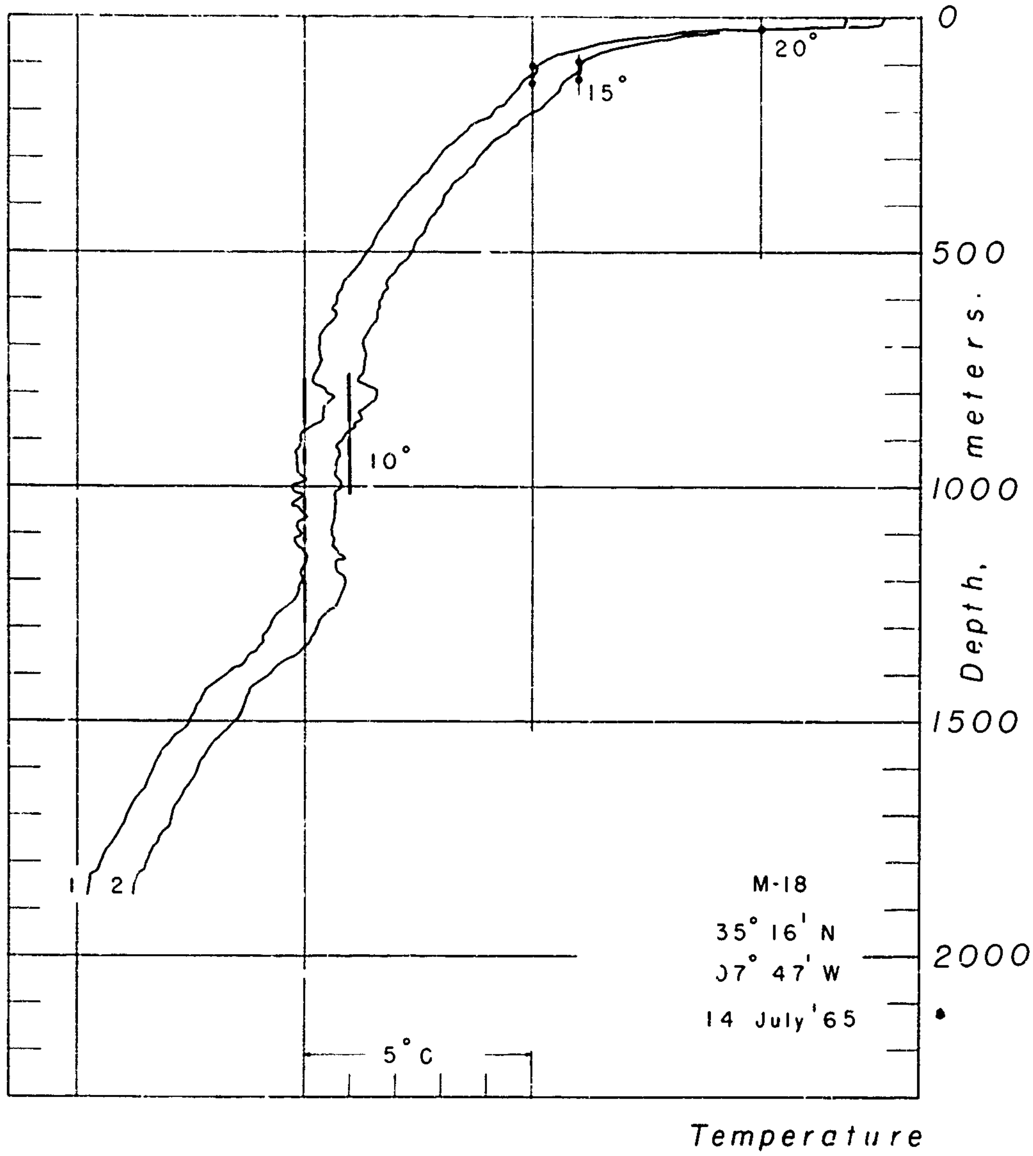


Fig. 36 *Temperatures*- Station M - 18

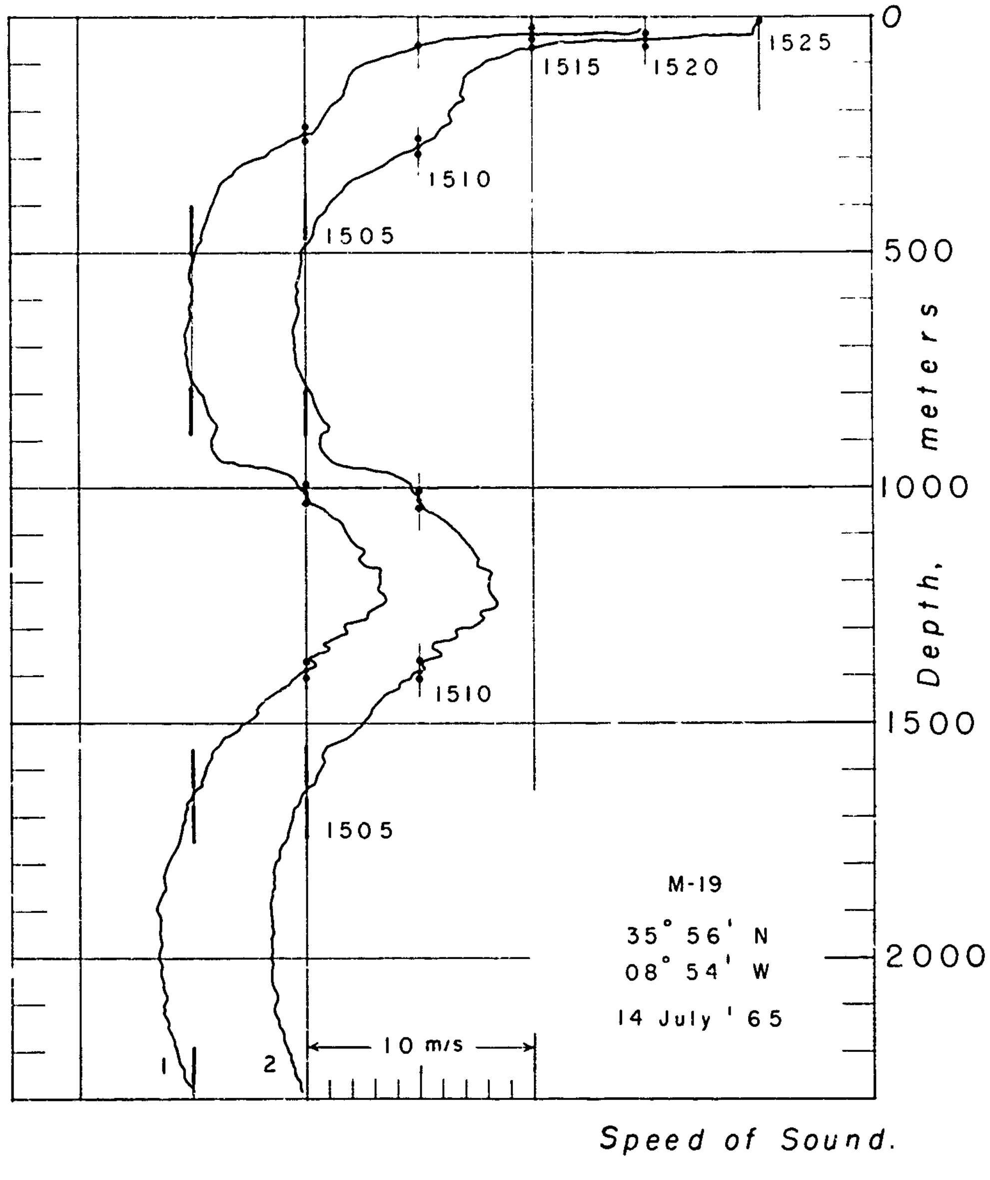
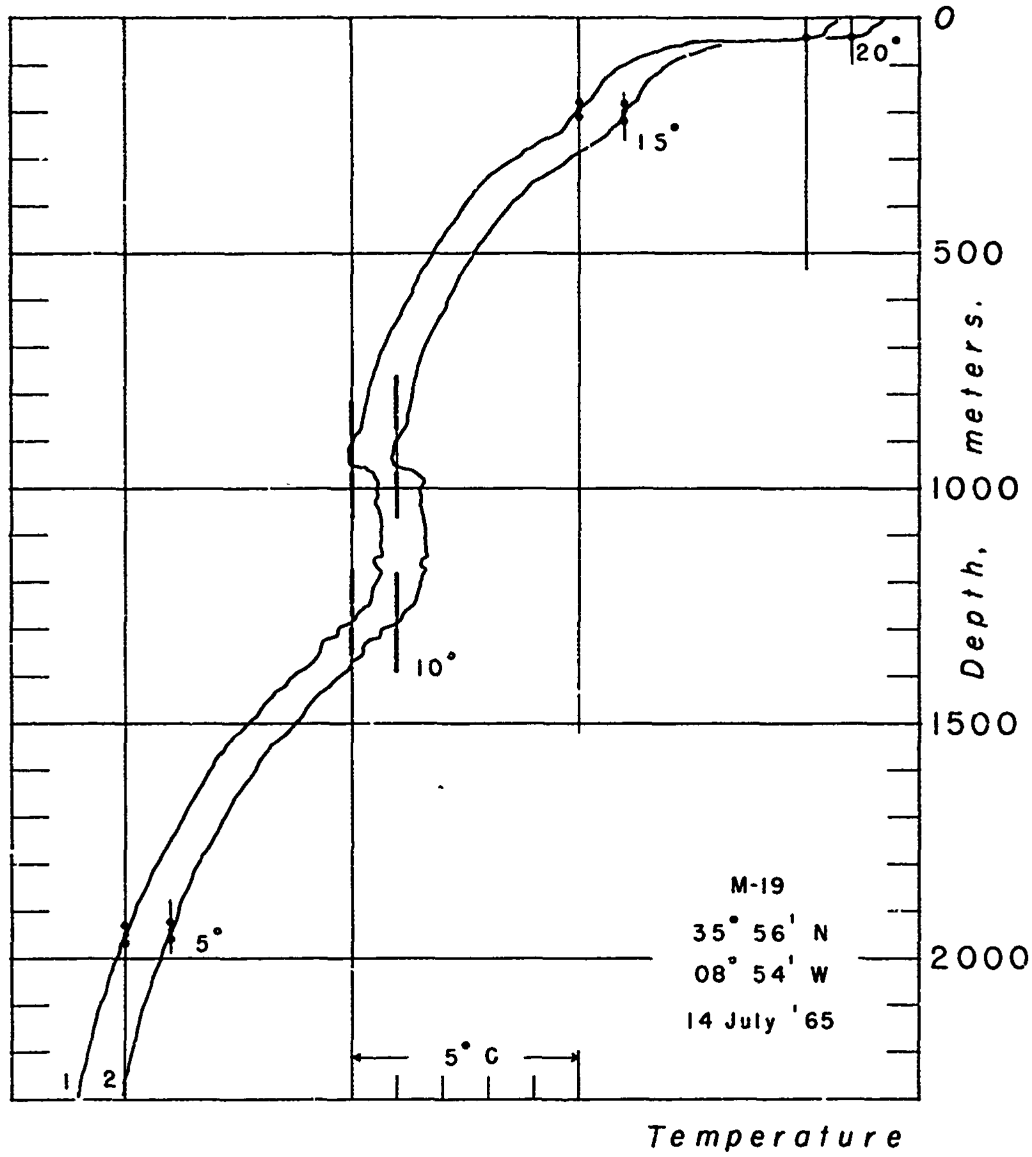


Fig. 37 Sound Speeds - Station M-19



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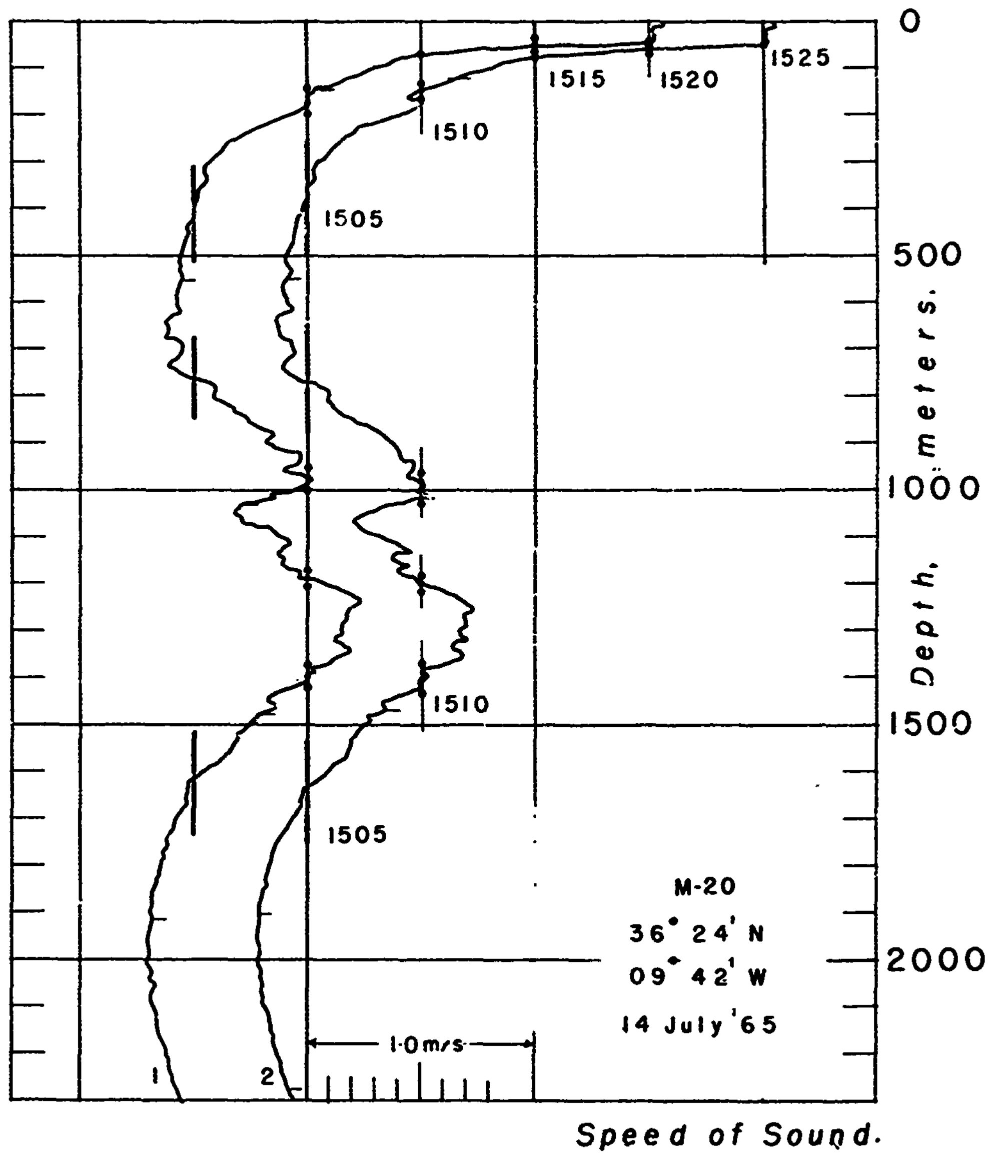

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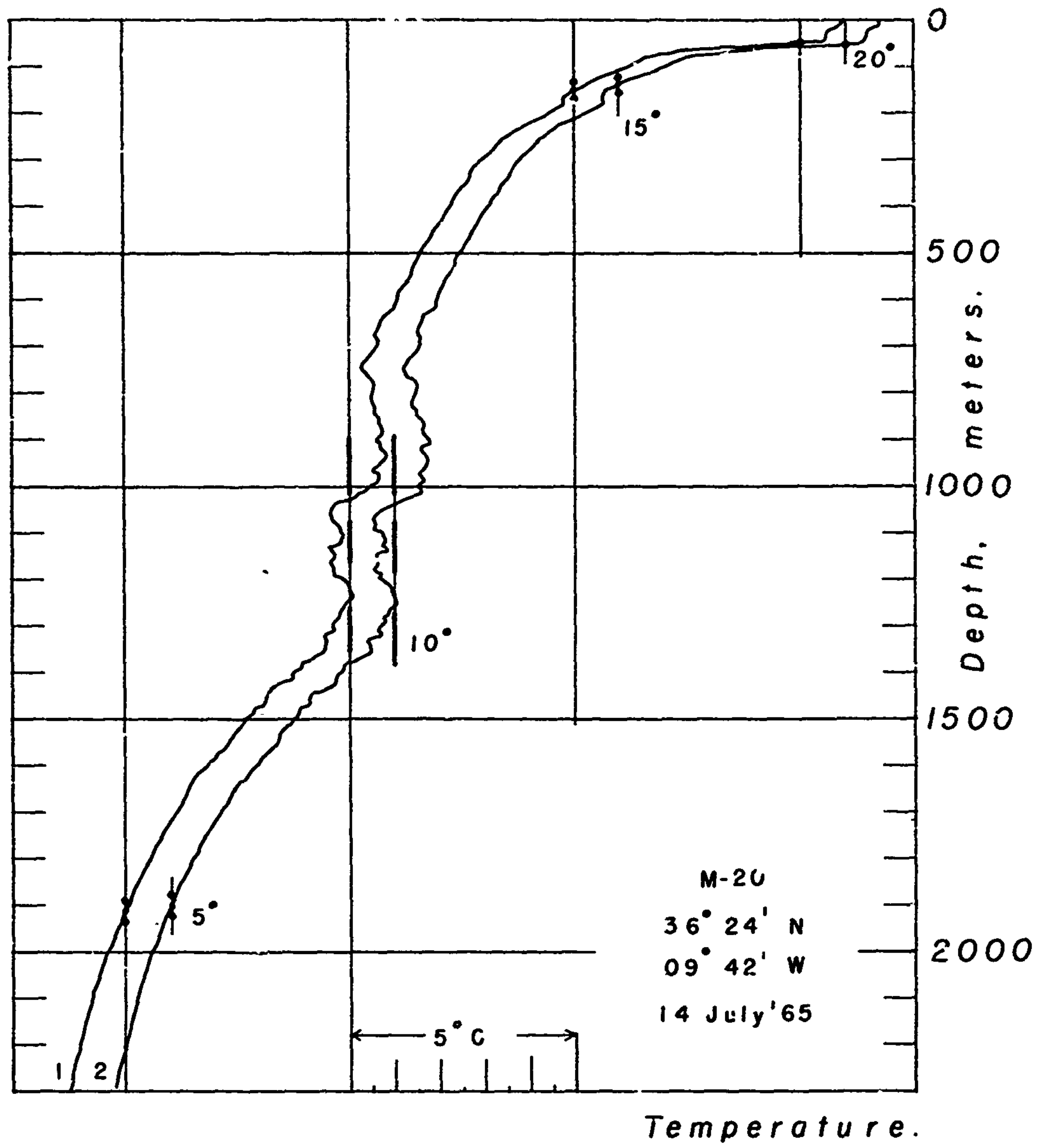

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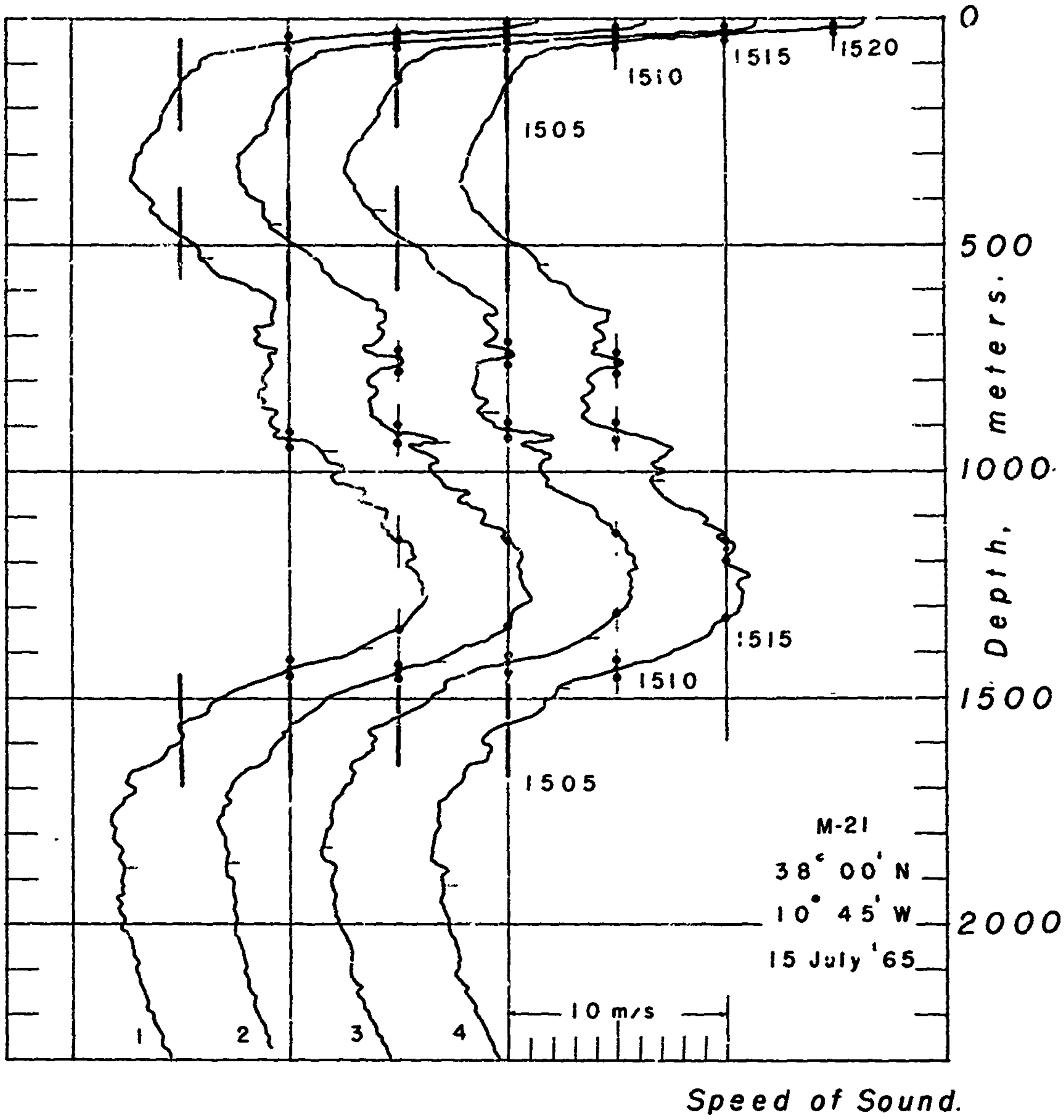

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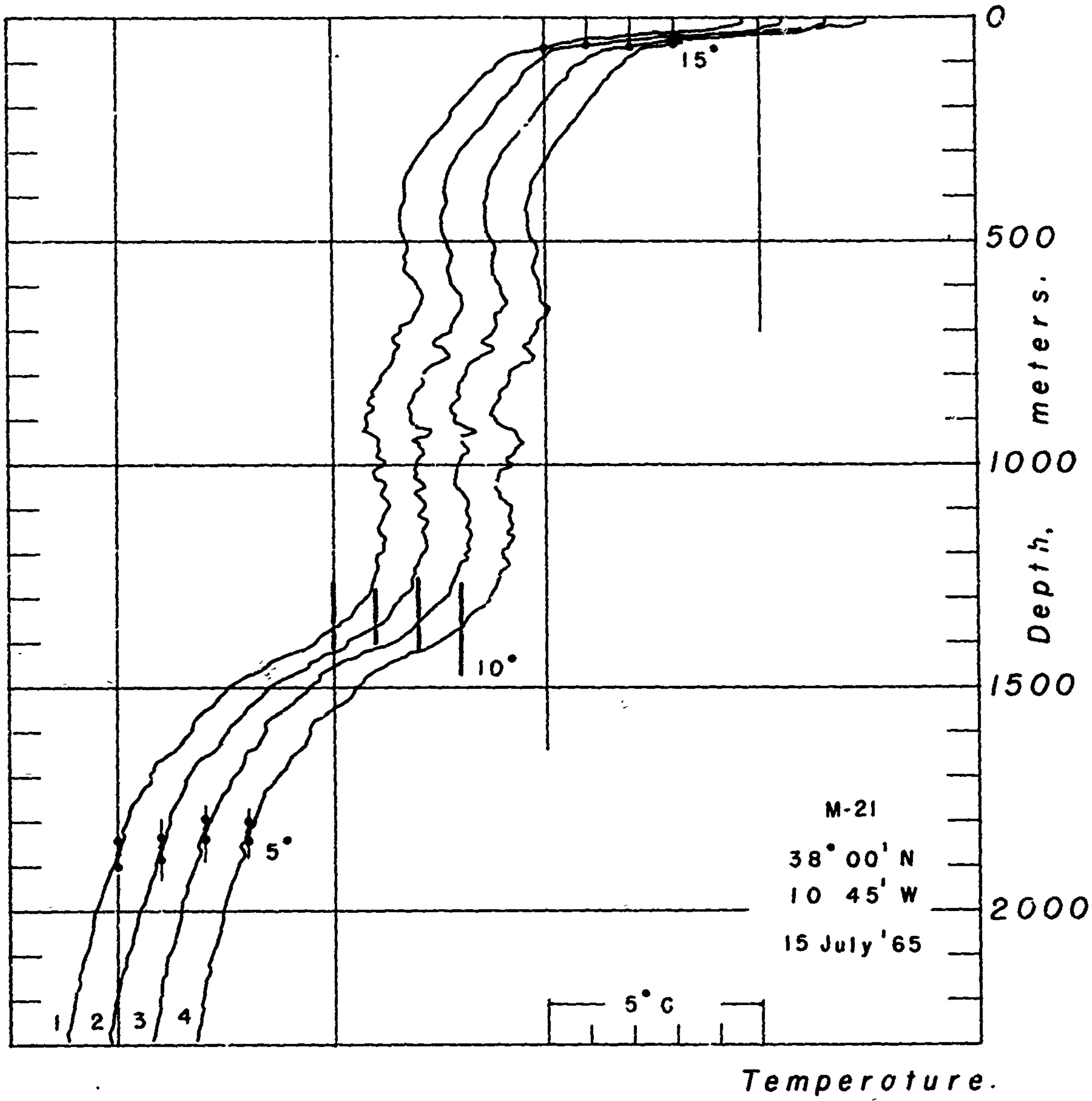

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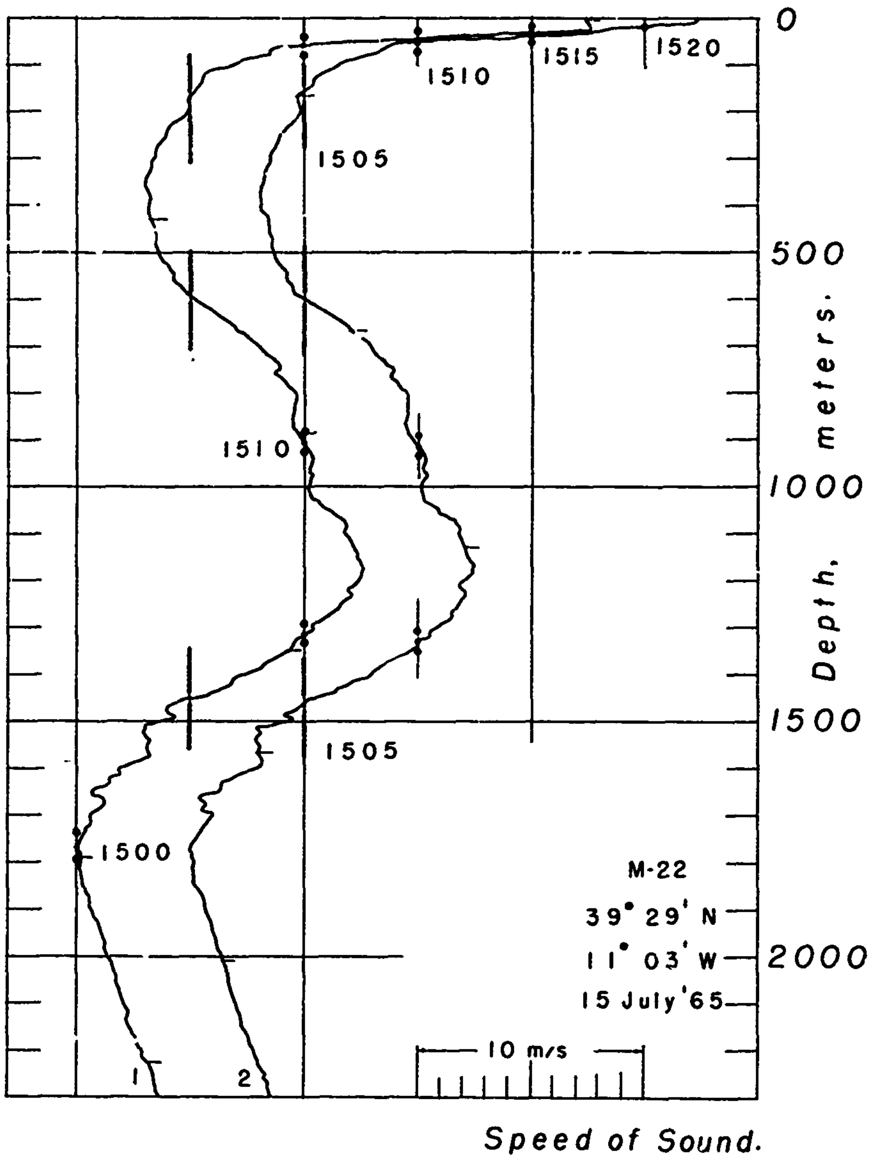

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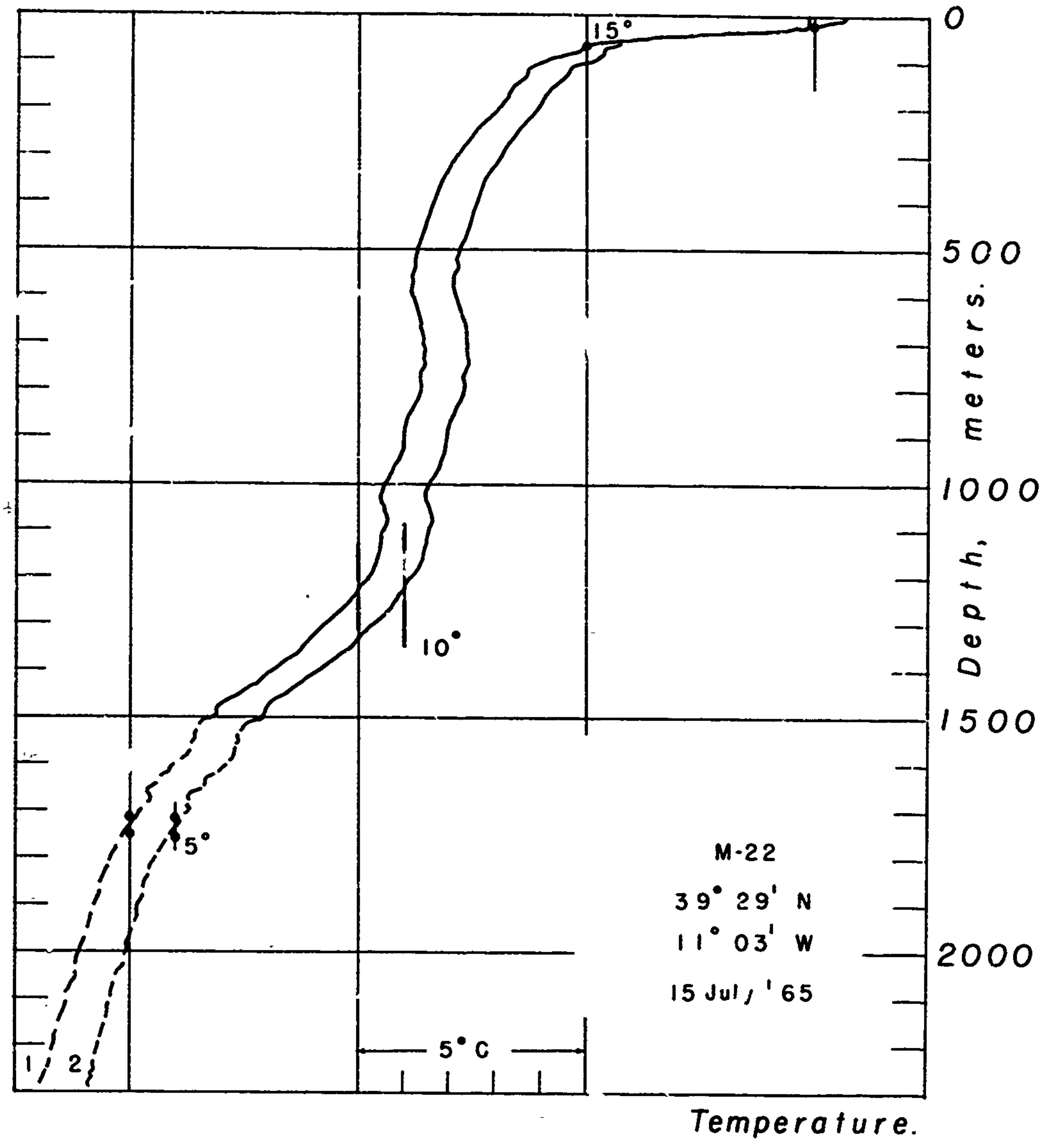

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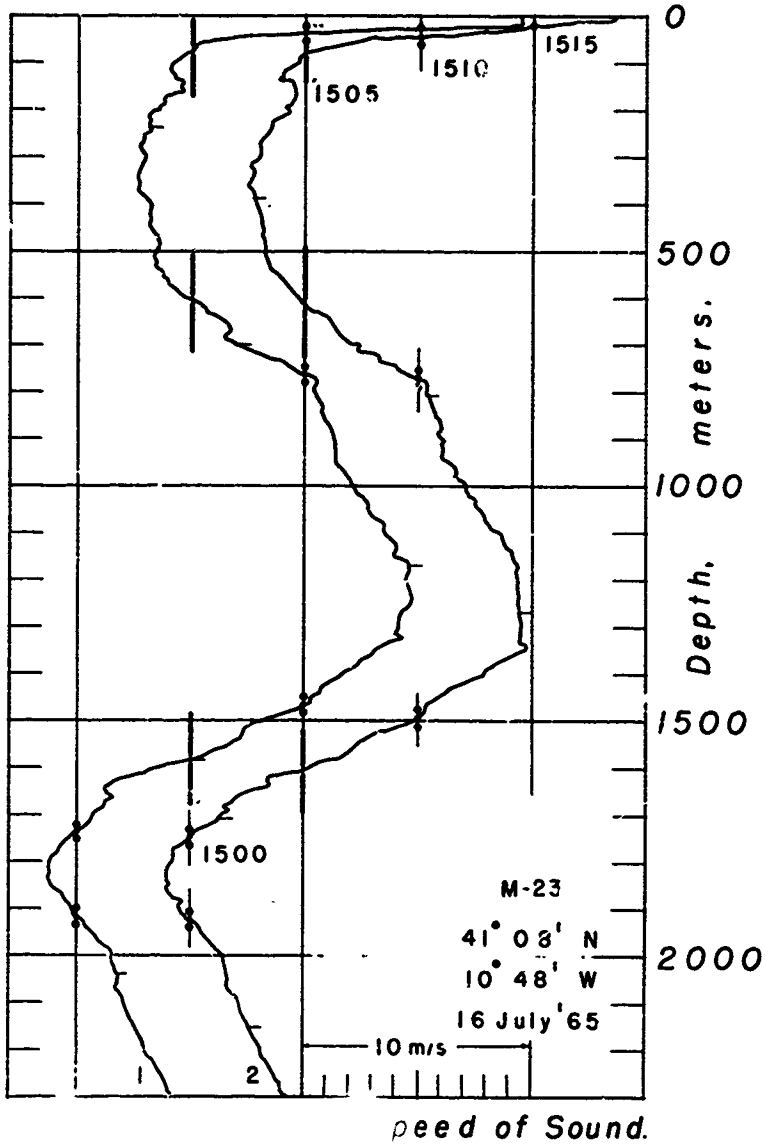
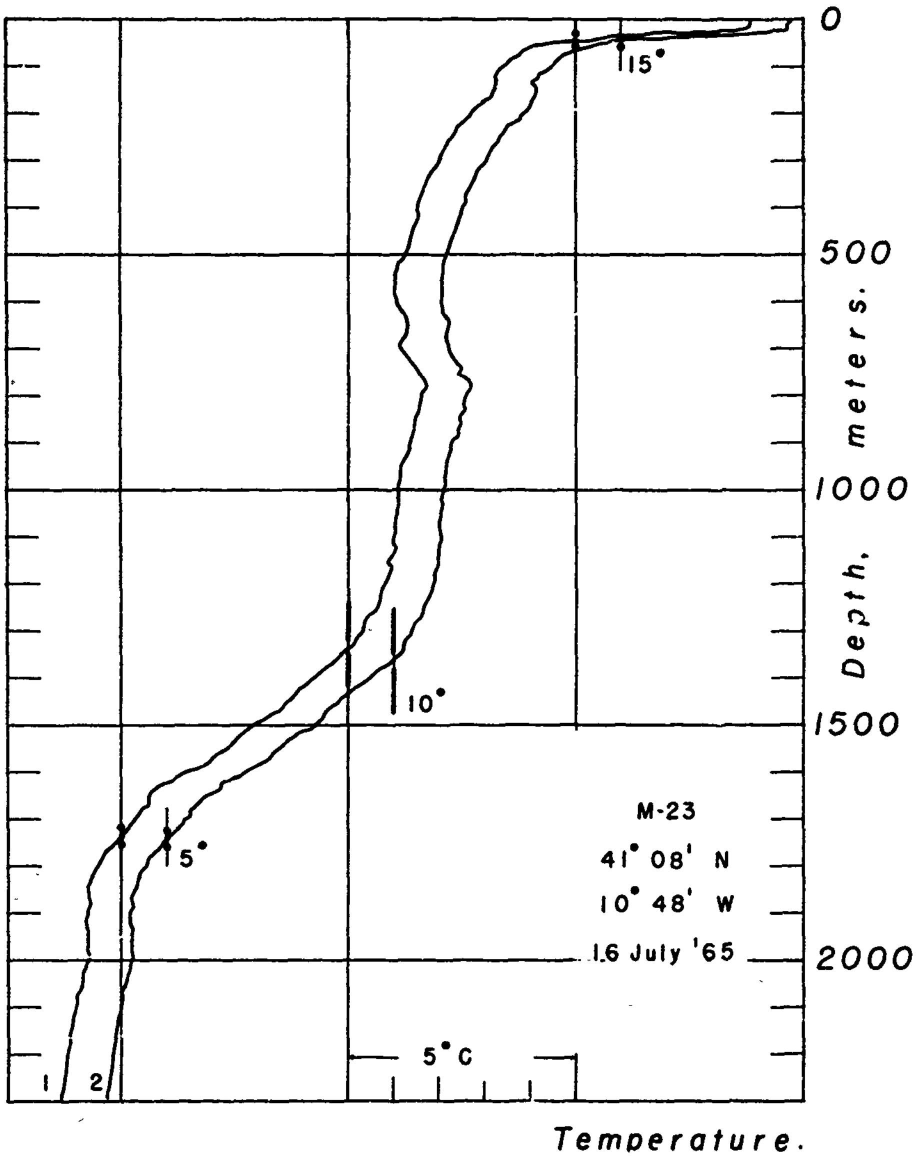


Fig. 45 Sound Speeds - Station M-23



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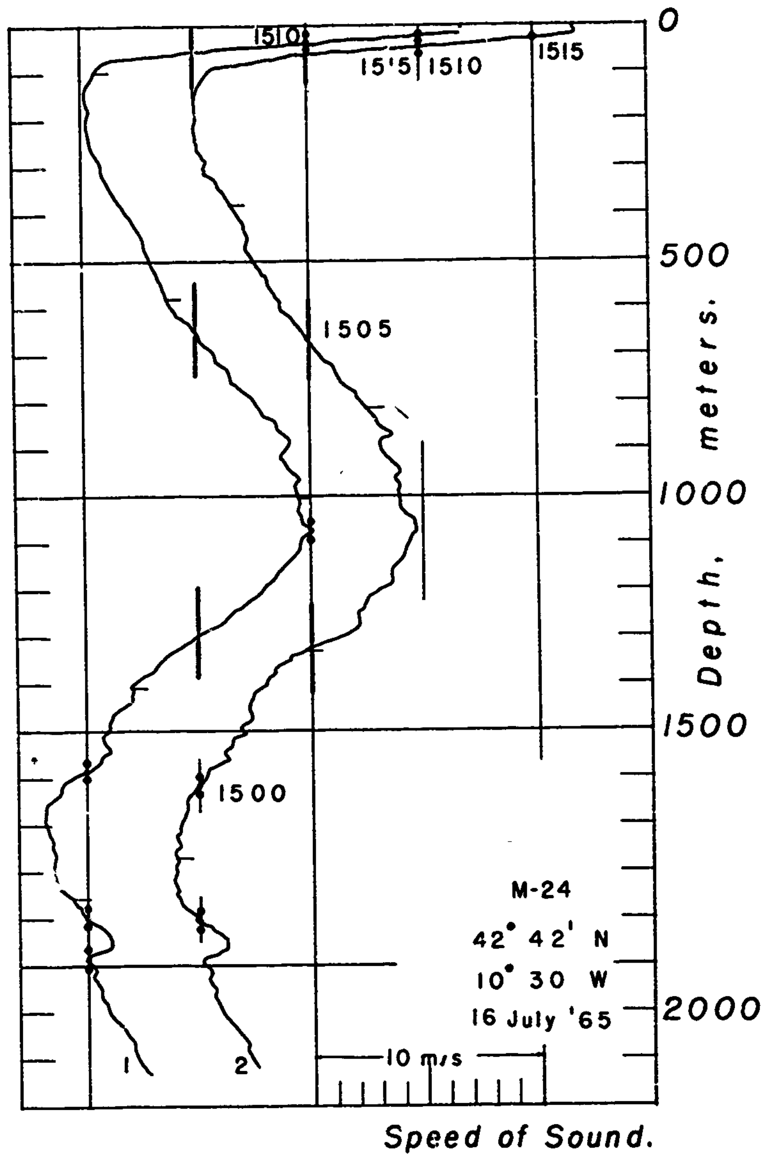
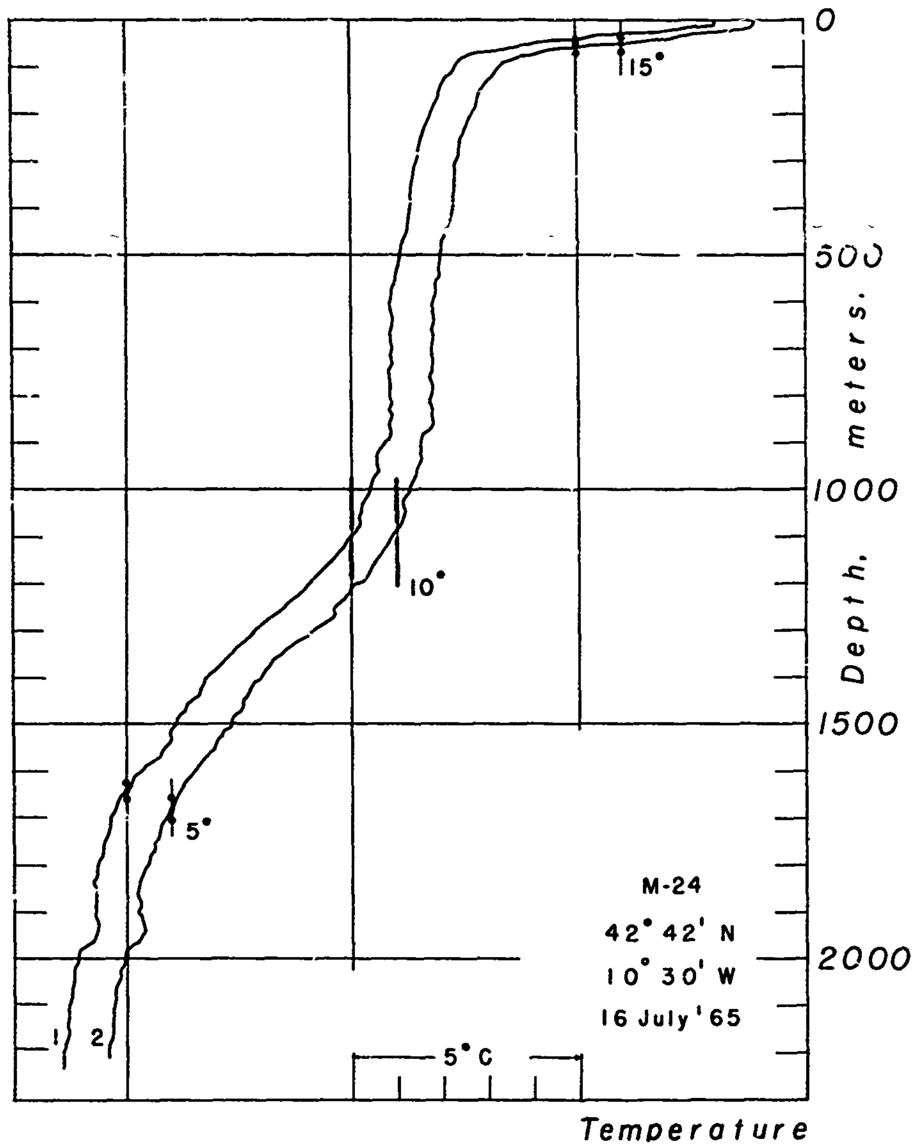


Fig. 47 *Sound Speeds* - Station M-24



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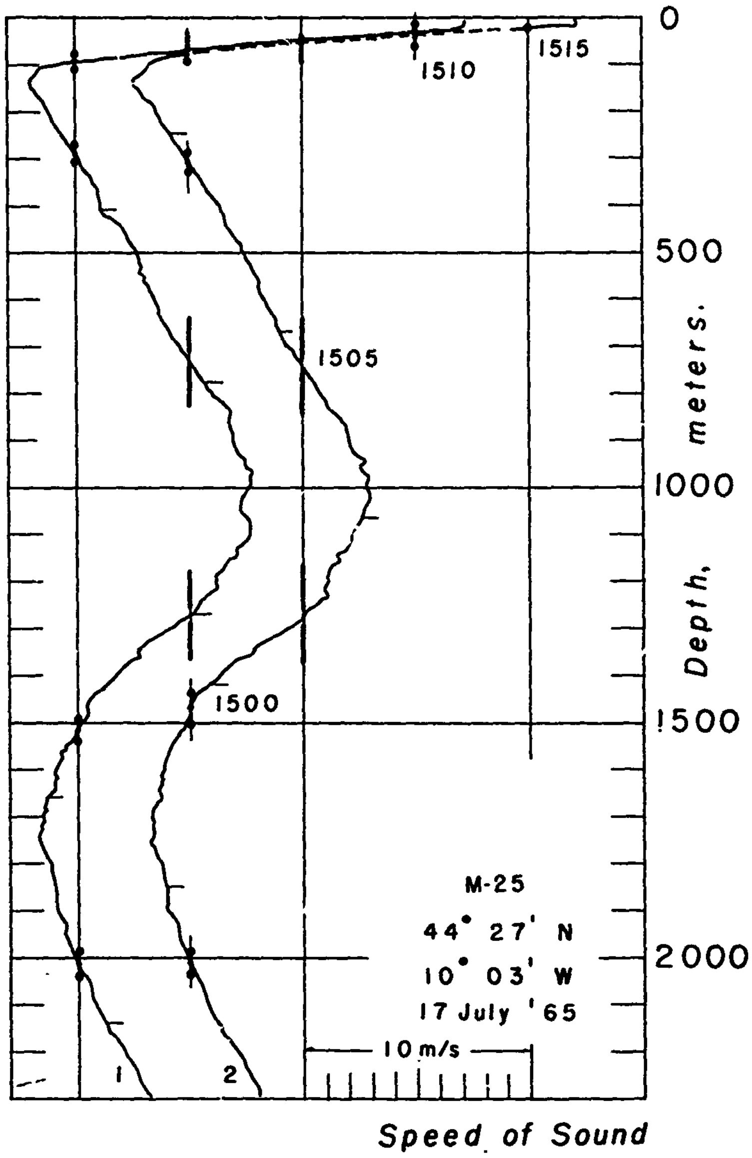


Fig. 49 Sound Speeds - Station M-25

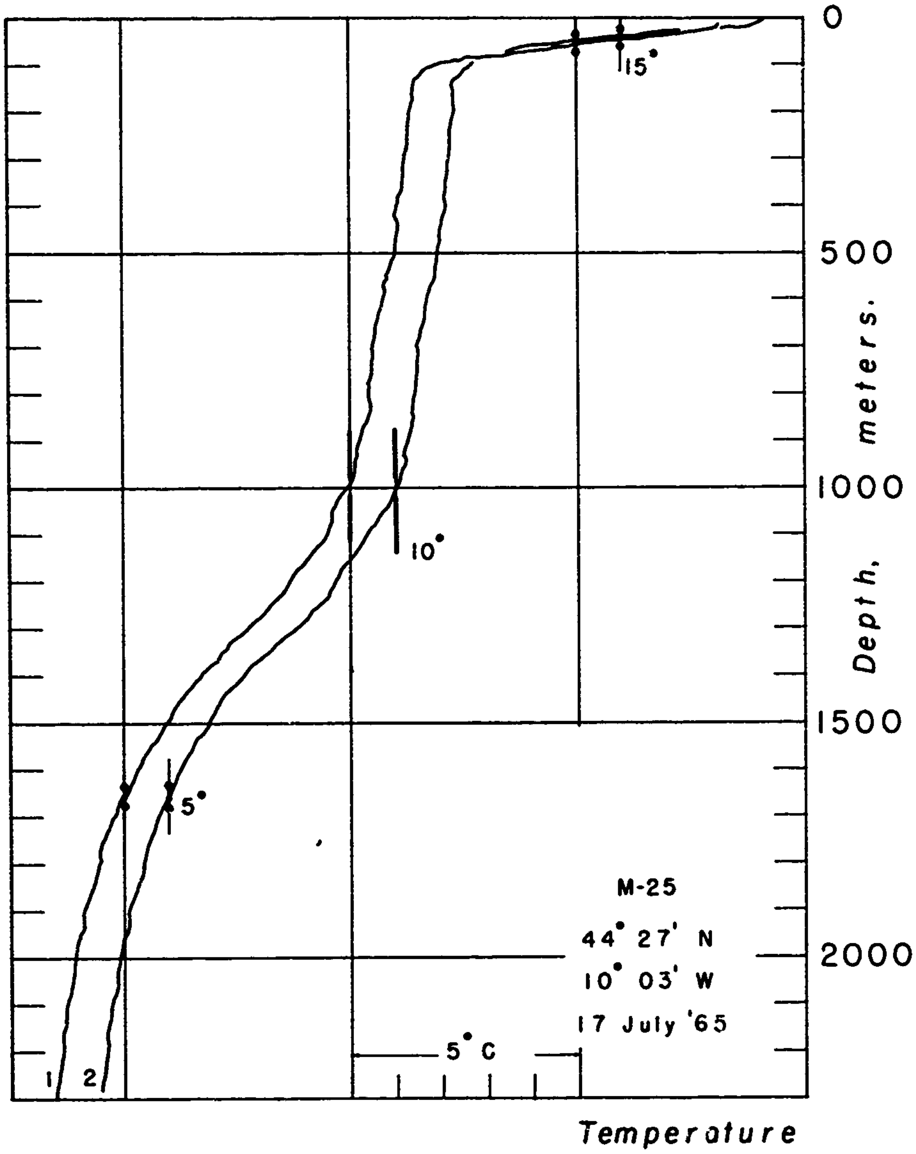


Fig. 50 *Temperatures* - Station M - 25

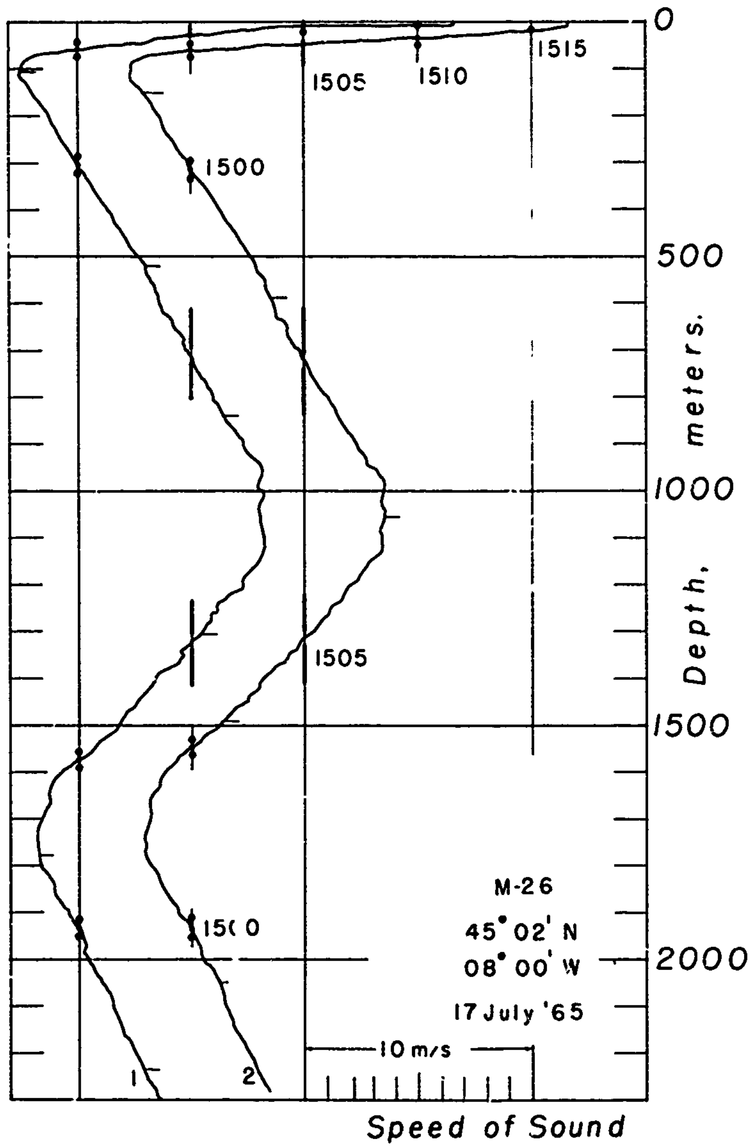


Fig. 51 *Sound Speeds* - Station M-26

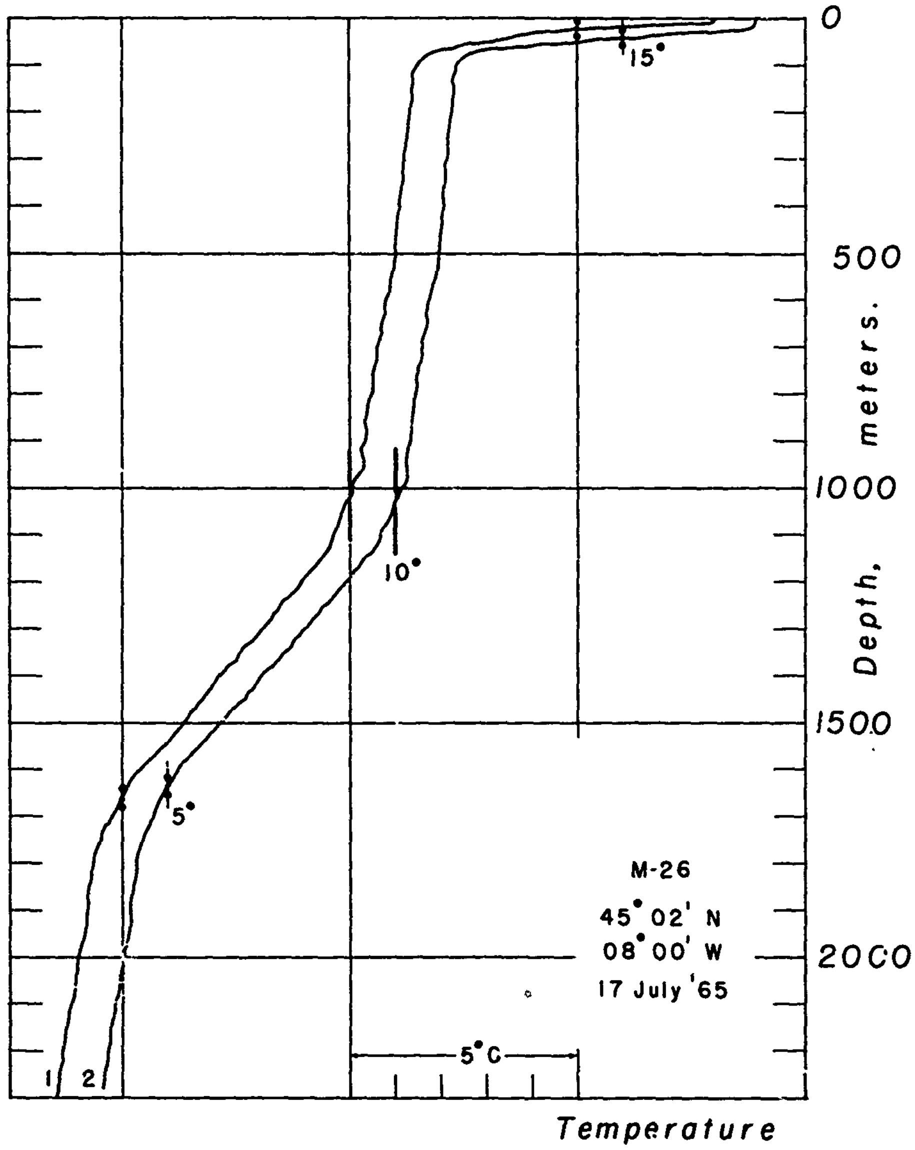


Fig. 52 *Temperatures* - Station M - 26

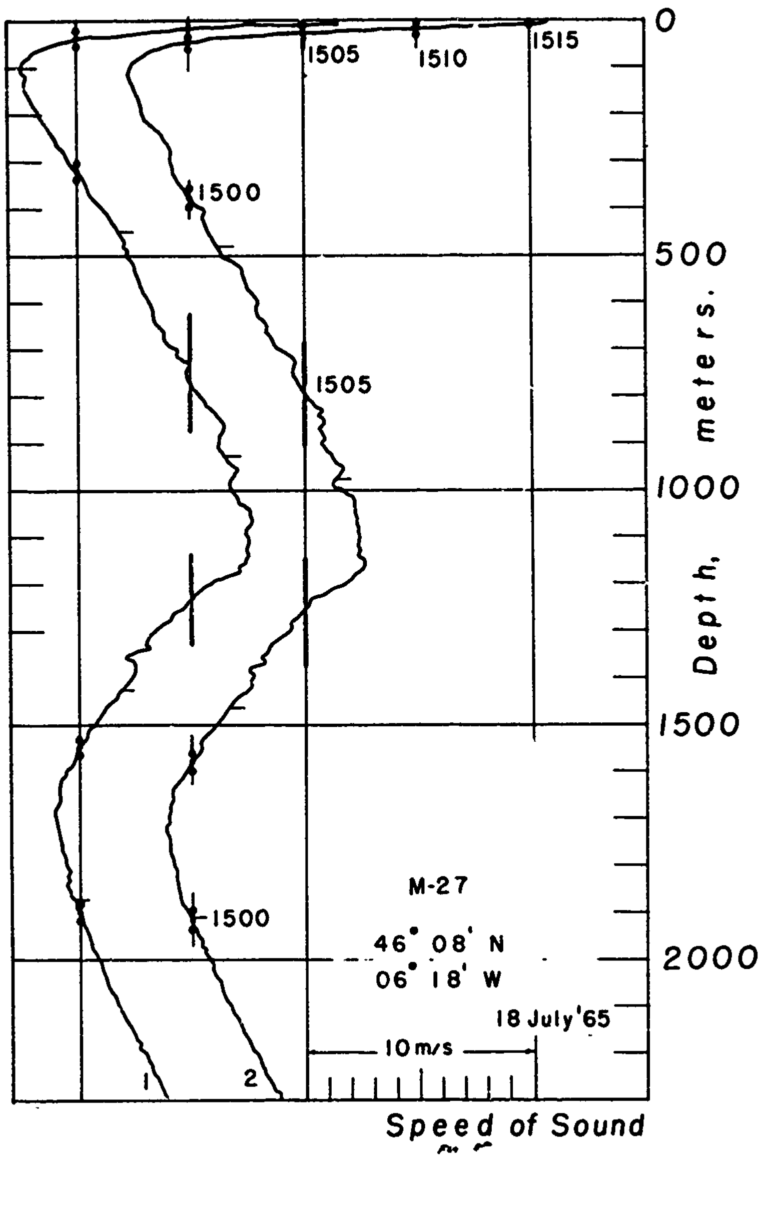


Fig. 53 *Sound Speeds* - Station M-27

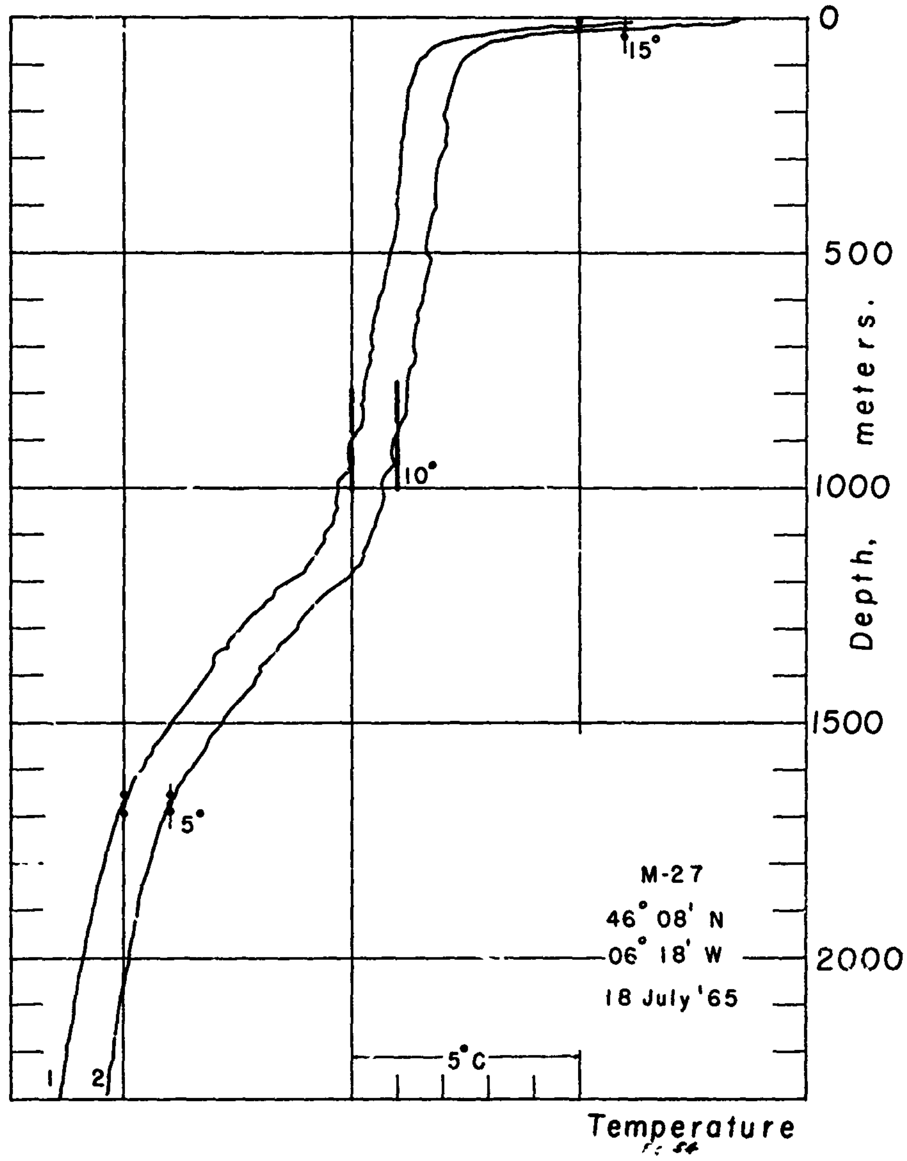


Fig. 54 Temperatures - Station M - 27

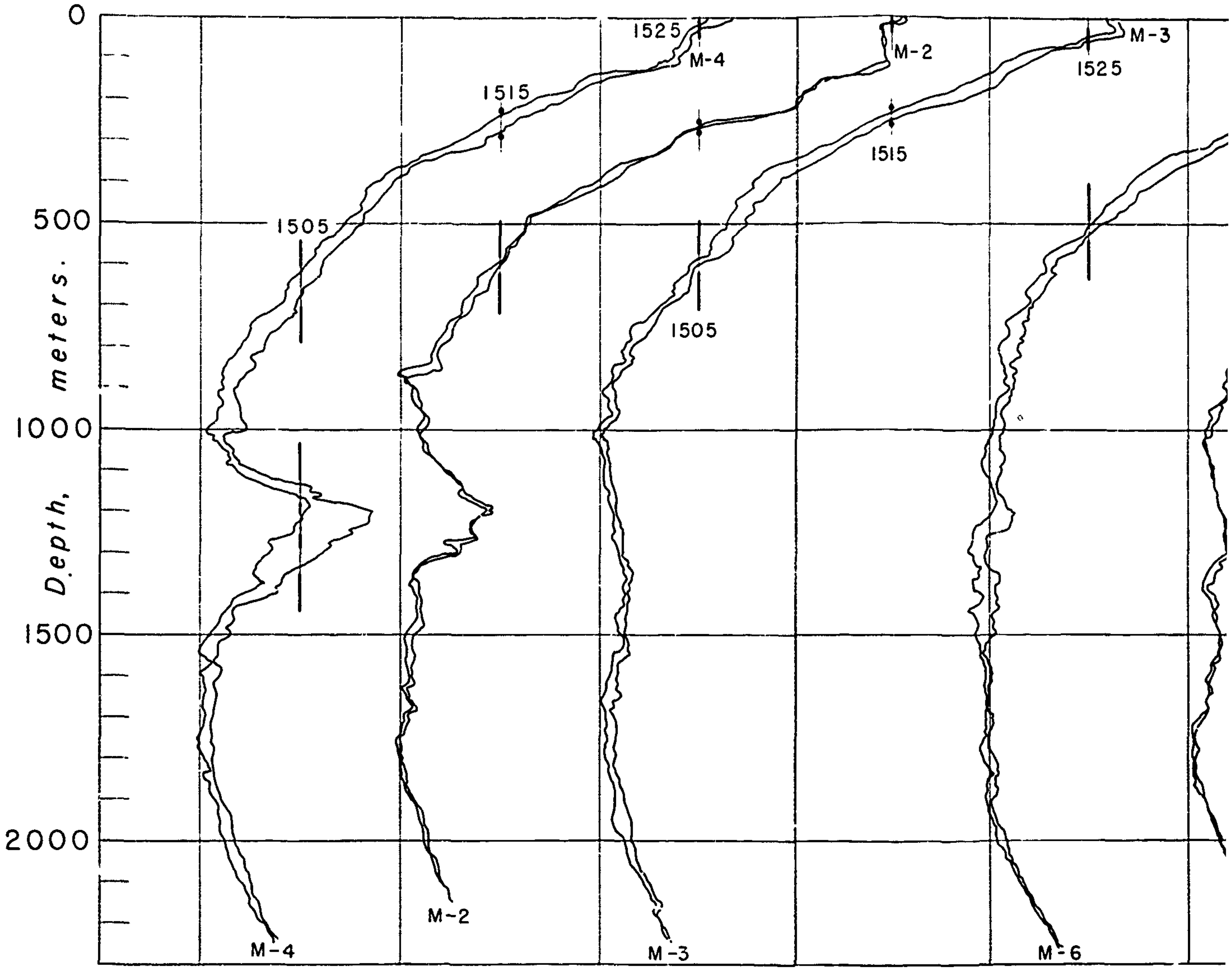
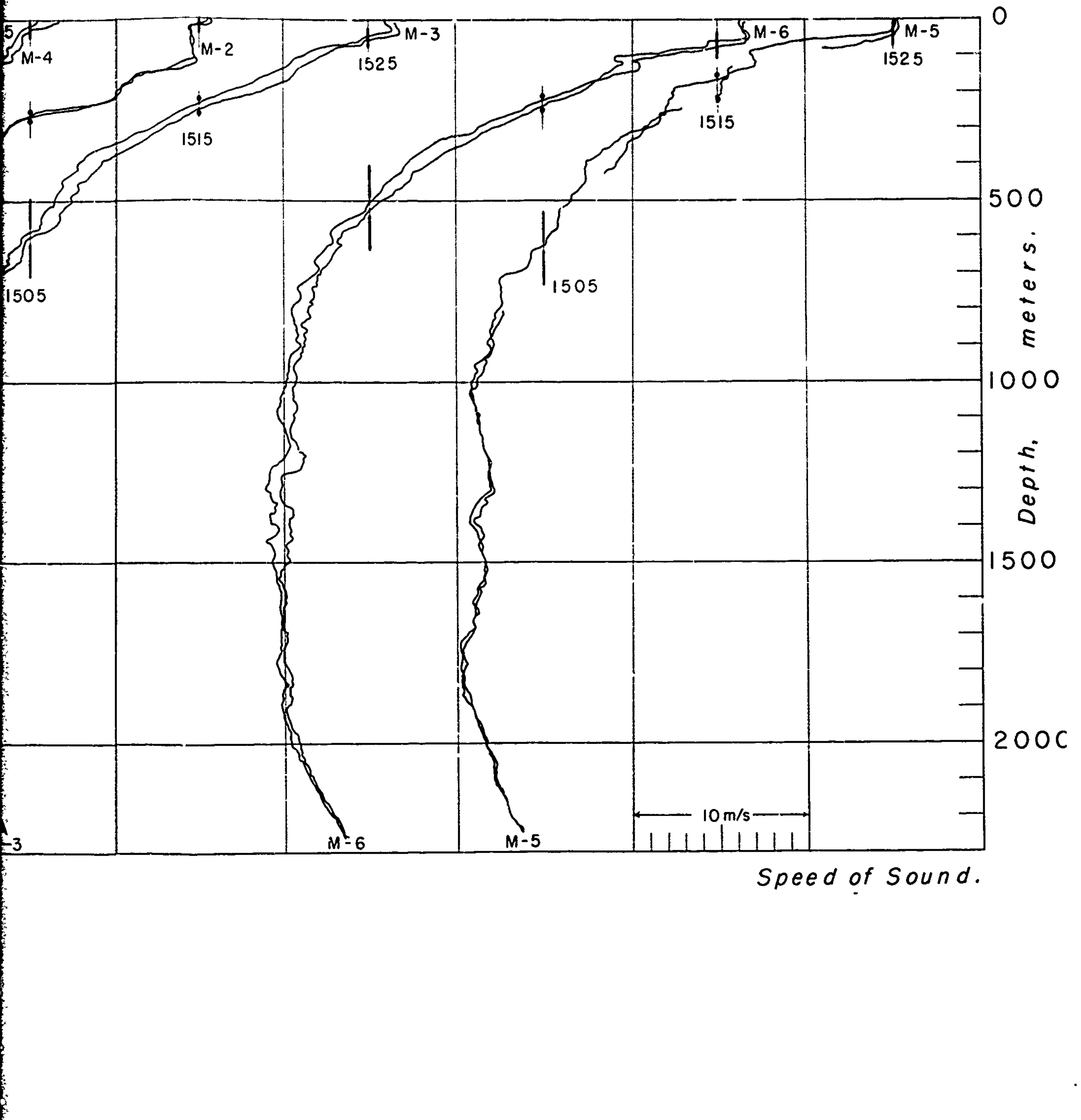


Fig. 55 *Envelopes of Sound Speed Profiles*, - Stations M-2

A



Sound Speed Profiles, - Stations M-2 to M-6 (Canaries)

13

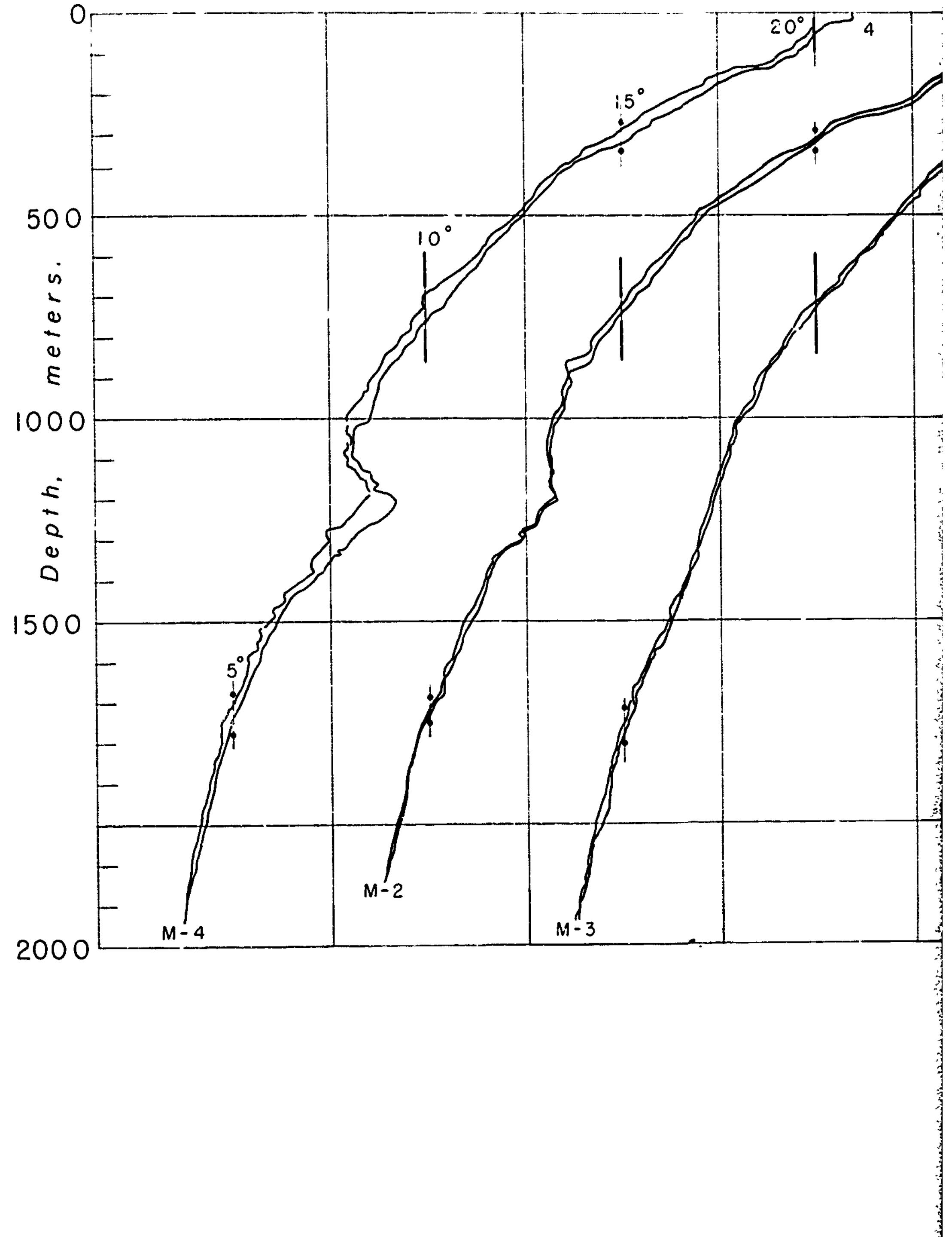
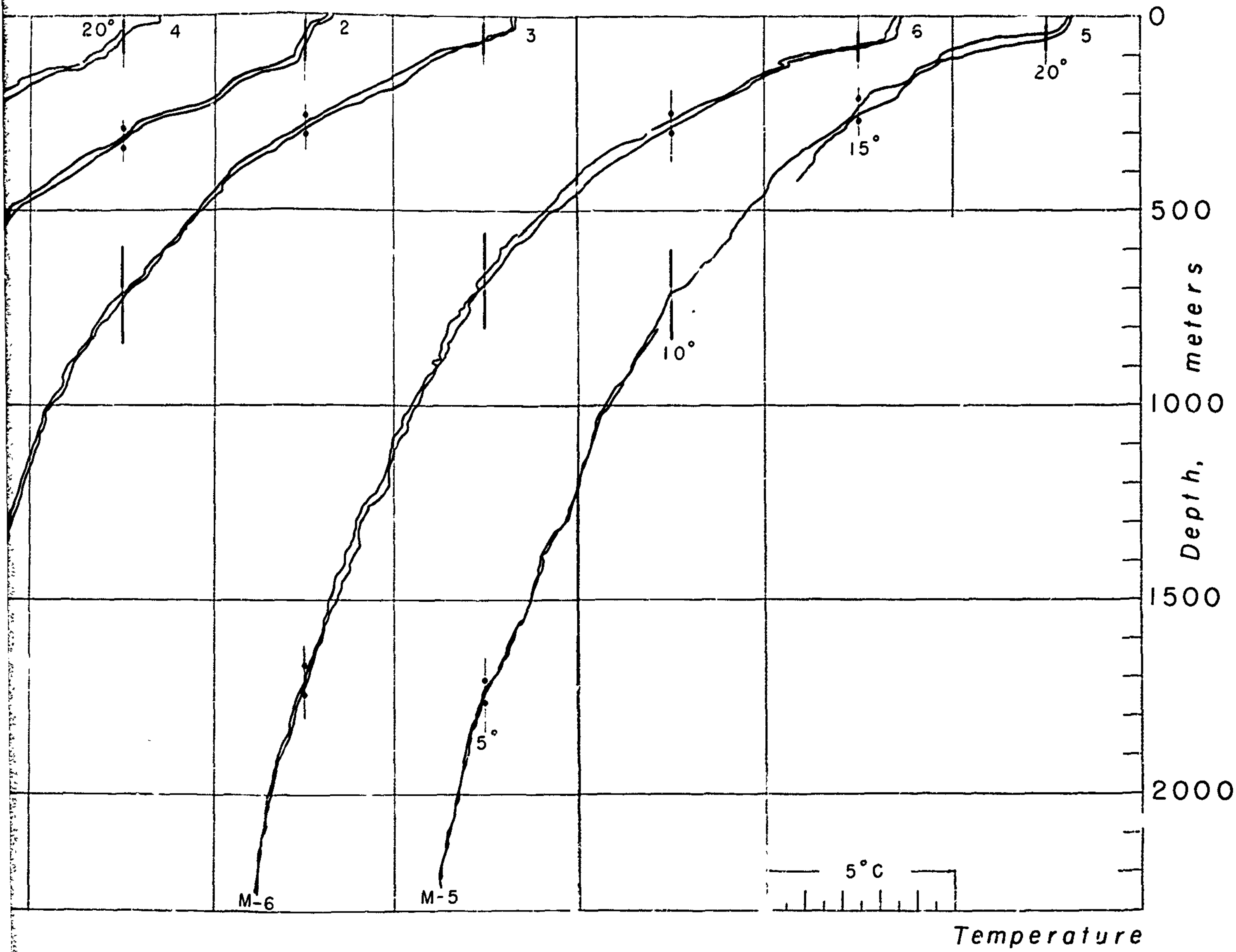


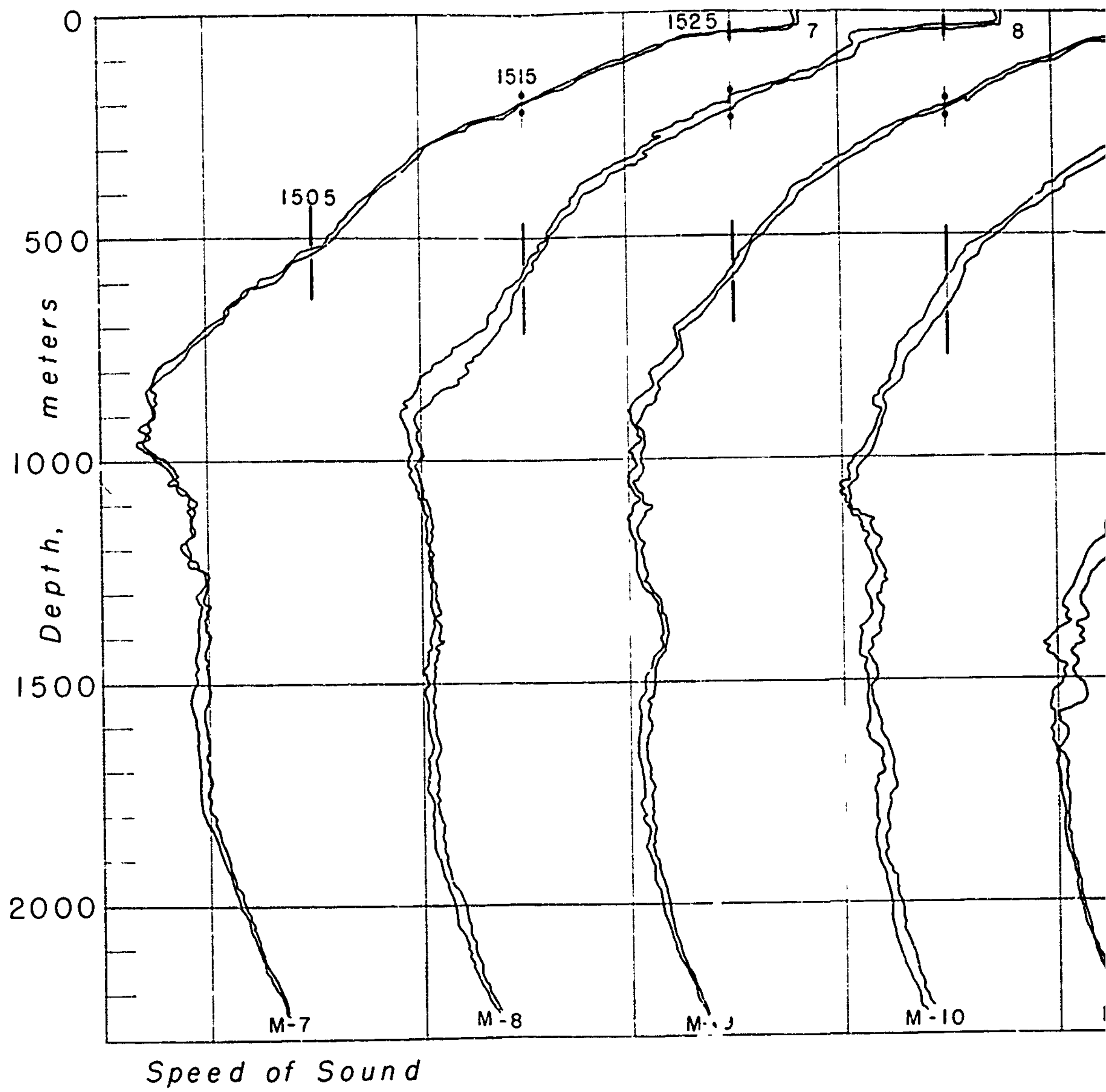
Fig. 56 *Envelopes of Temperature*

A



f Temperature Profiles,-Stations M-2 to M-6 (Canaries)

B



0
500
1000
1500
2000
Depth, meters
1505
1515
1525
7
8
M-7
M-8
M-10
Speed of Sound

A

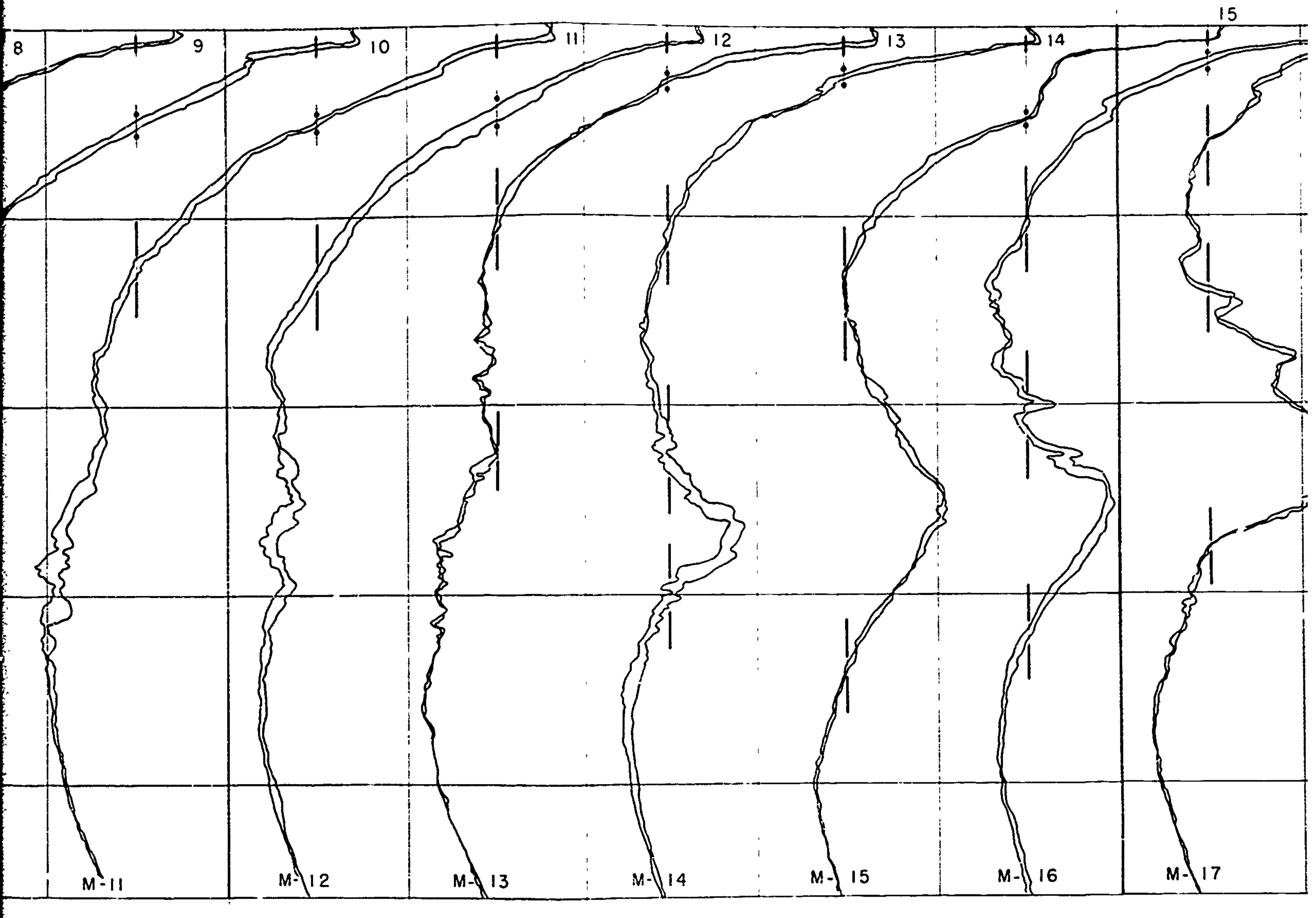
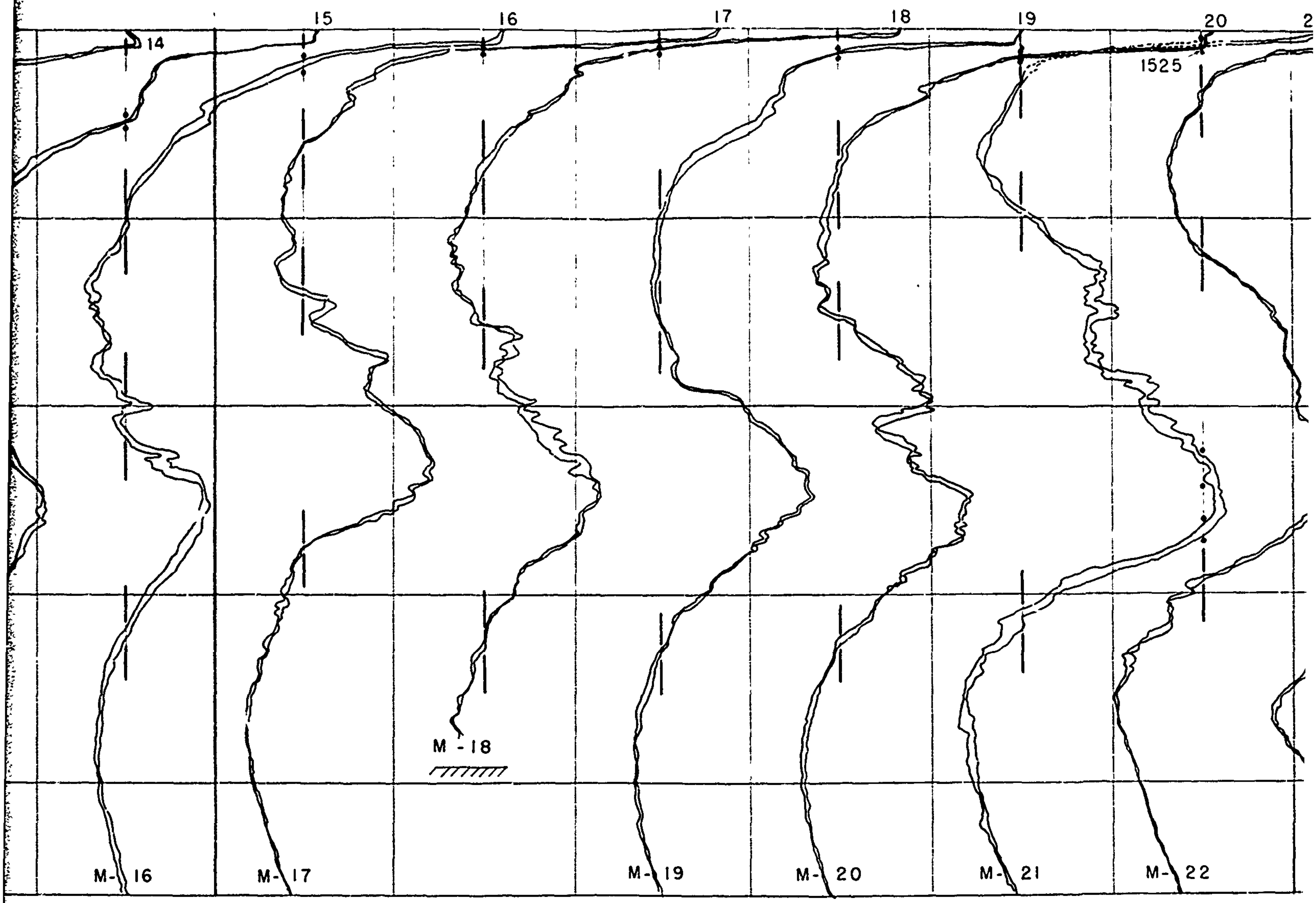


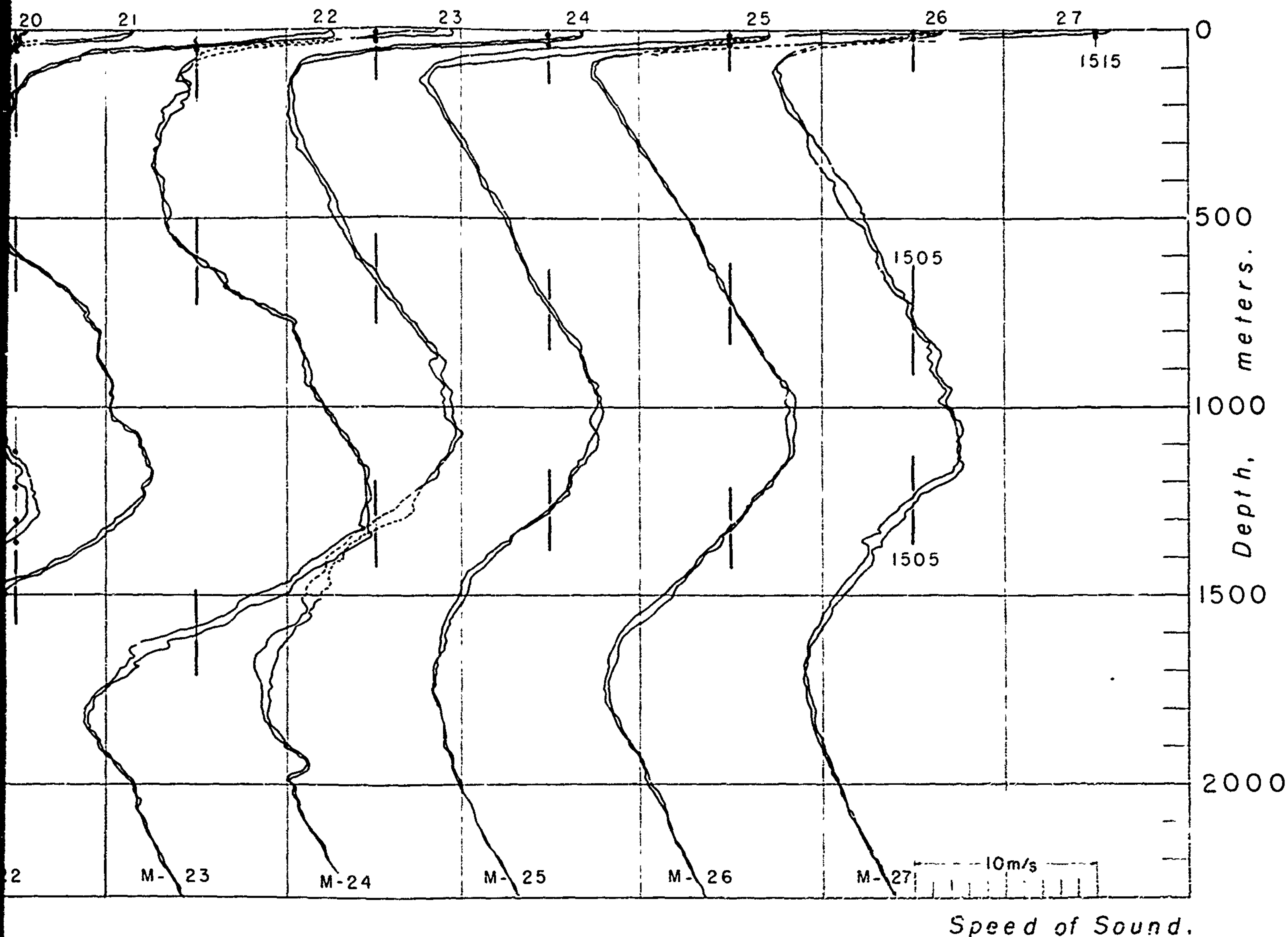
Fig. 57 *Envelopes of Sound Speed Profiles, -Sta*

B



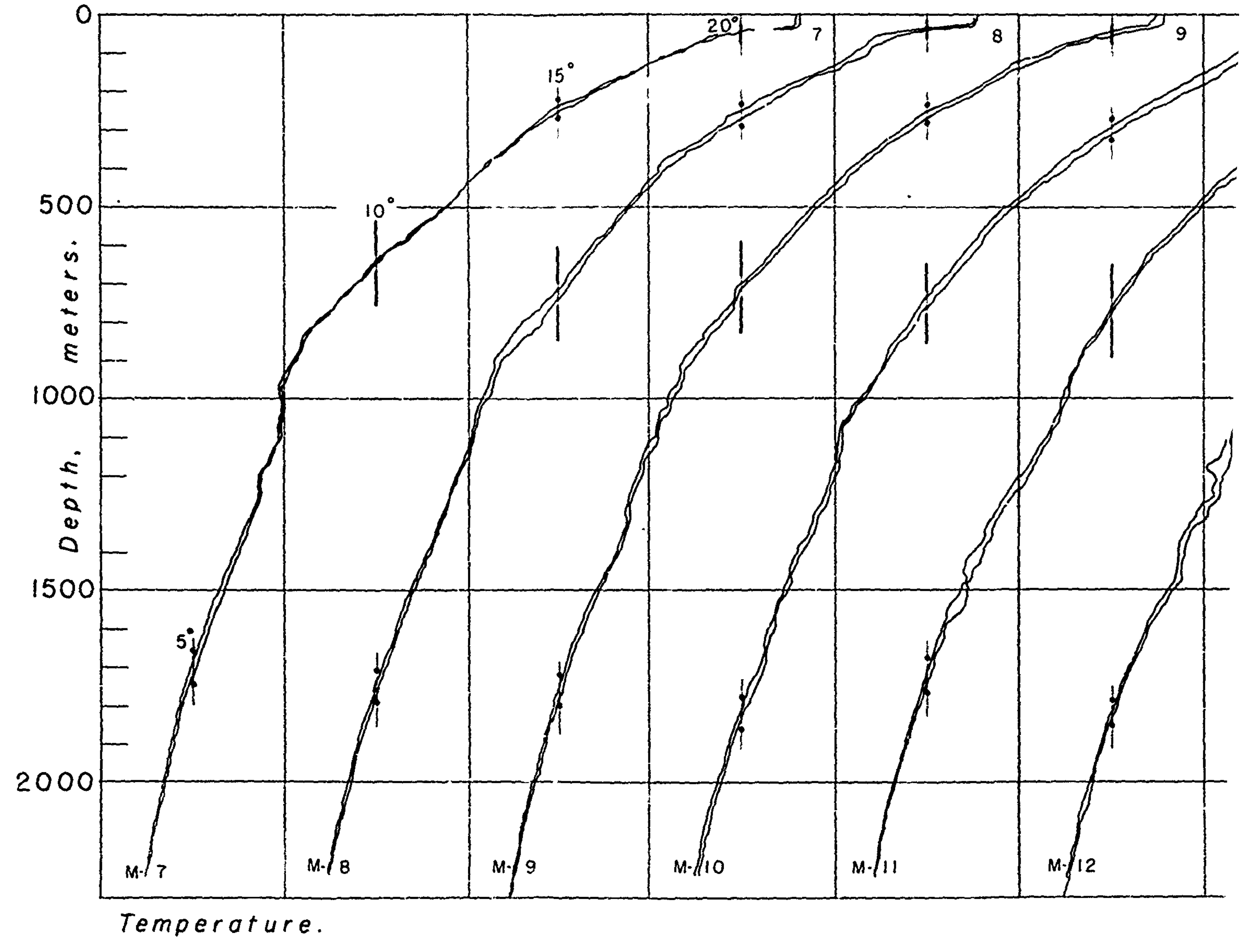
Sound Speed Profiles, - Stations M-7 to M-27 (Canaries to Bay of Biscay)

C


20
21
22
23
24
25
26
27
0
1515
500
1505
1000
1505
1500
2000
Depth, meters.
2
M-23
M-24
M-25
M-26
M-27
10m/s
Speed of Sound.

7

D



0
500
1000
1500
2000
Depth, meters.
20°
15°
10°
5°
7
8
9
M-7
M-8
M-9
M-10
M-11
M-12
Temperature.

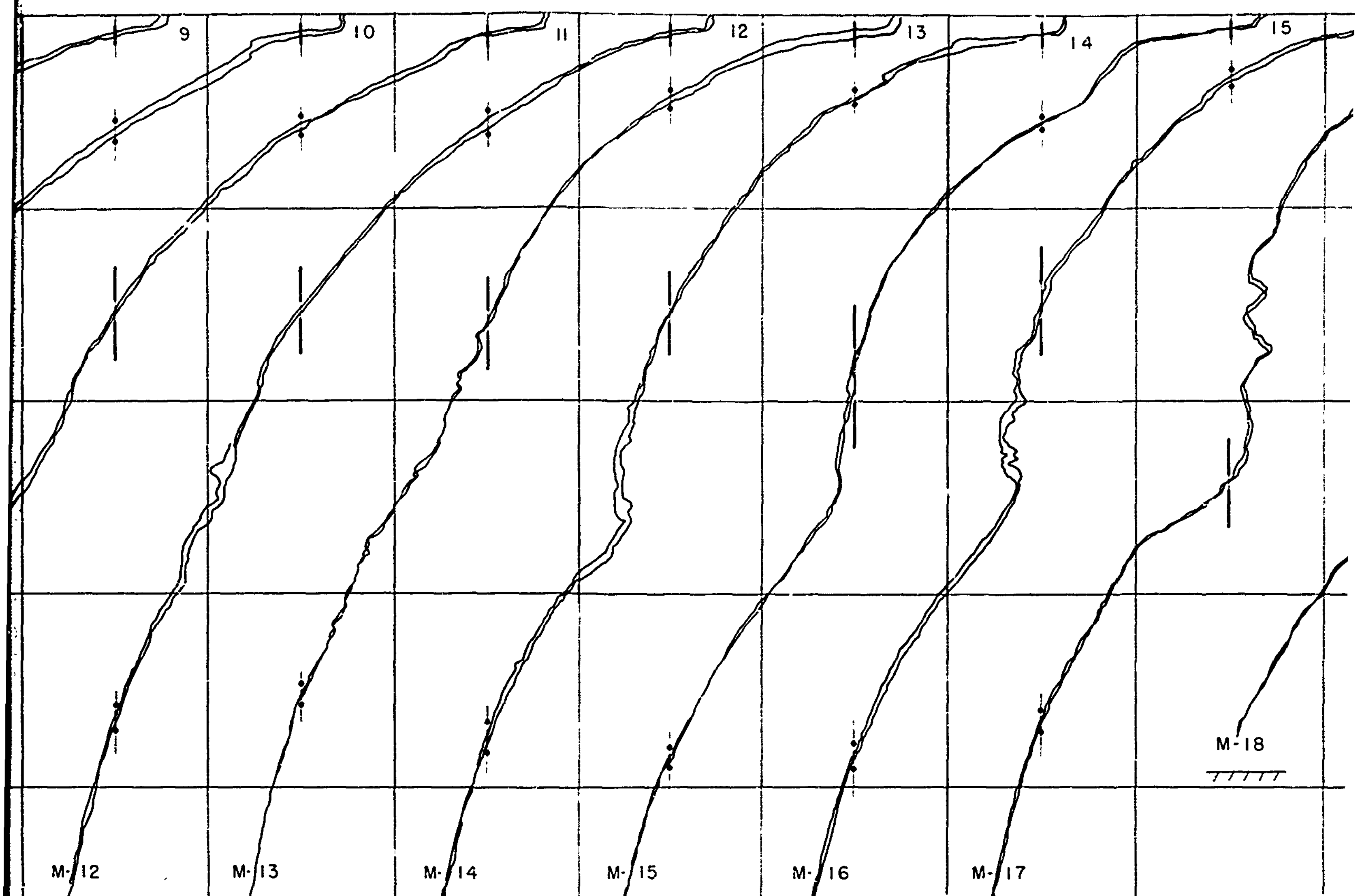
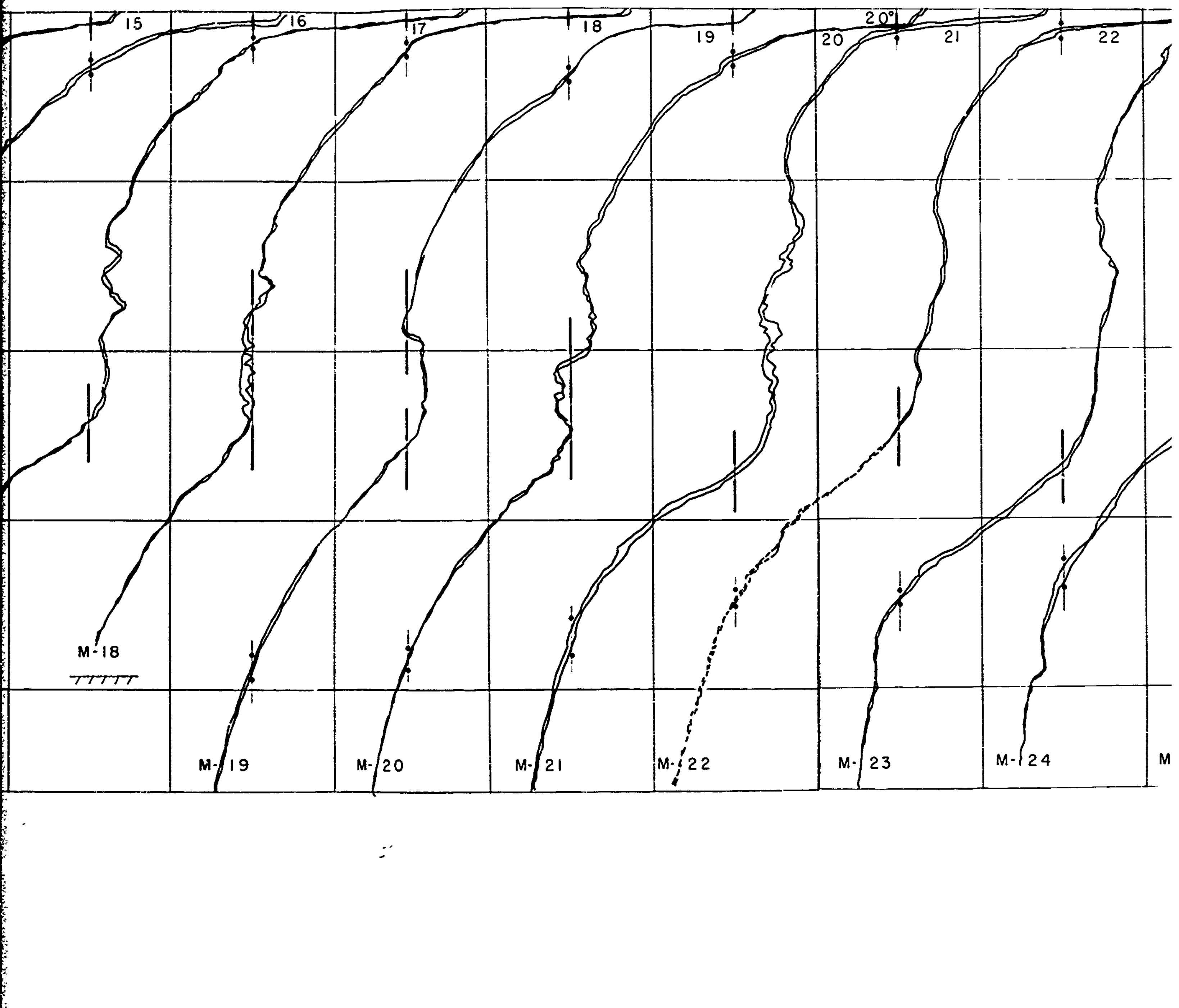
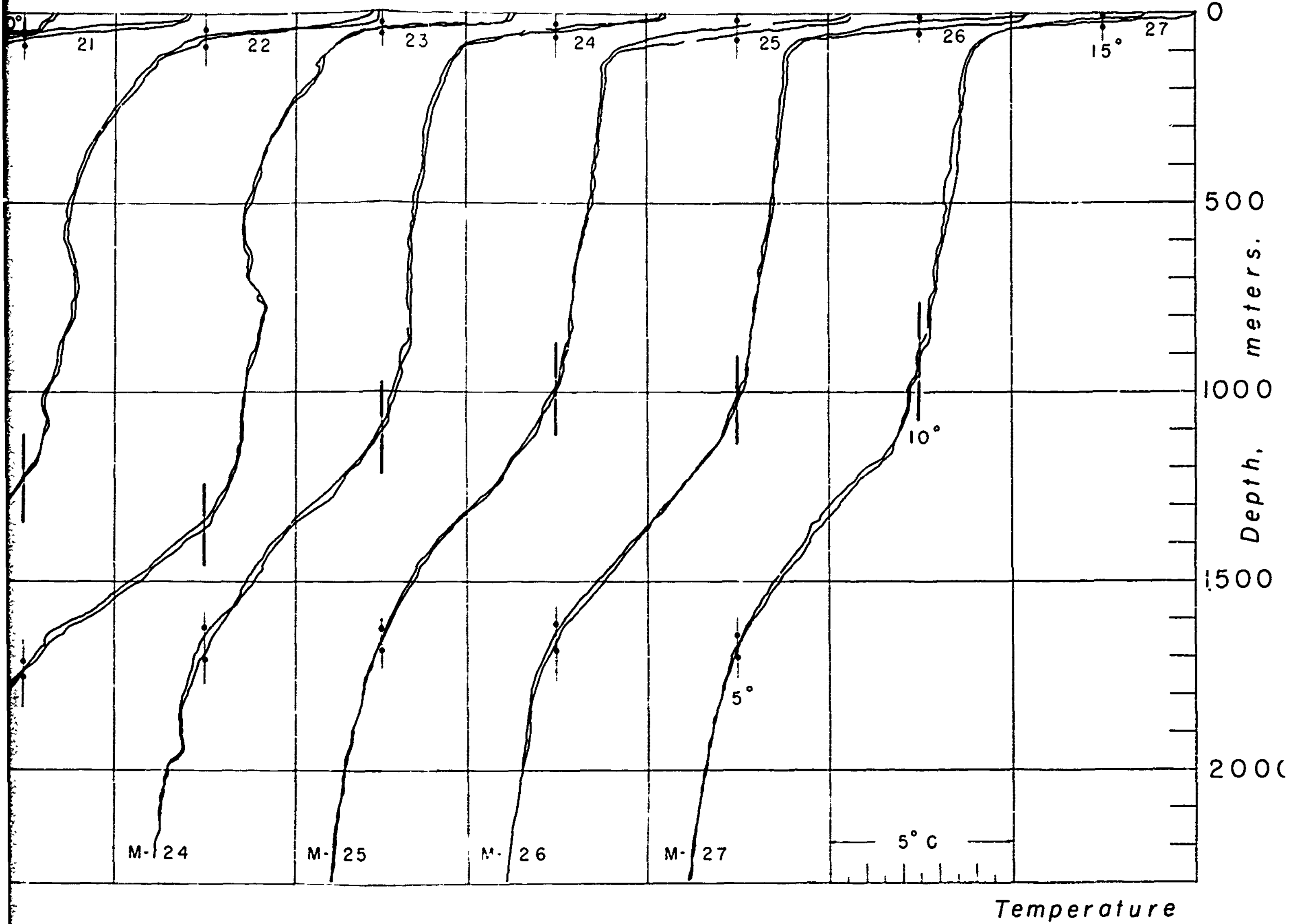


Fig. 58 *Envelopes of Temperature Profiles,-Stations M*



les, - Stations M-7 to M-27 (Canaries to Bay of Biscay)

C



0
500
1000
1500
2000
Depth, meters.
21
22
23
24
25
26
27
15°
10°
5°
M-24
M-25
M-26
M-27
5° C
Temperature

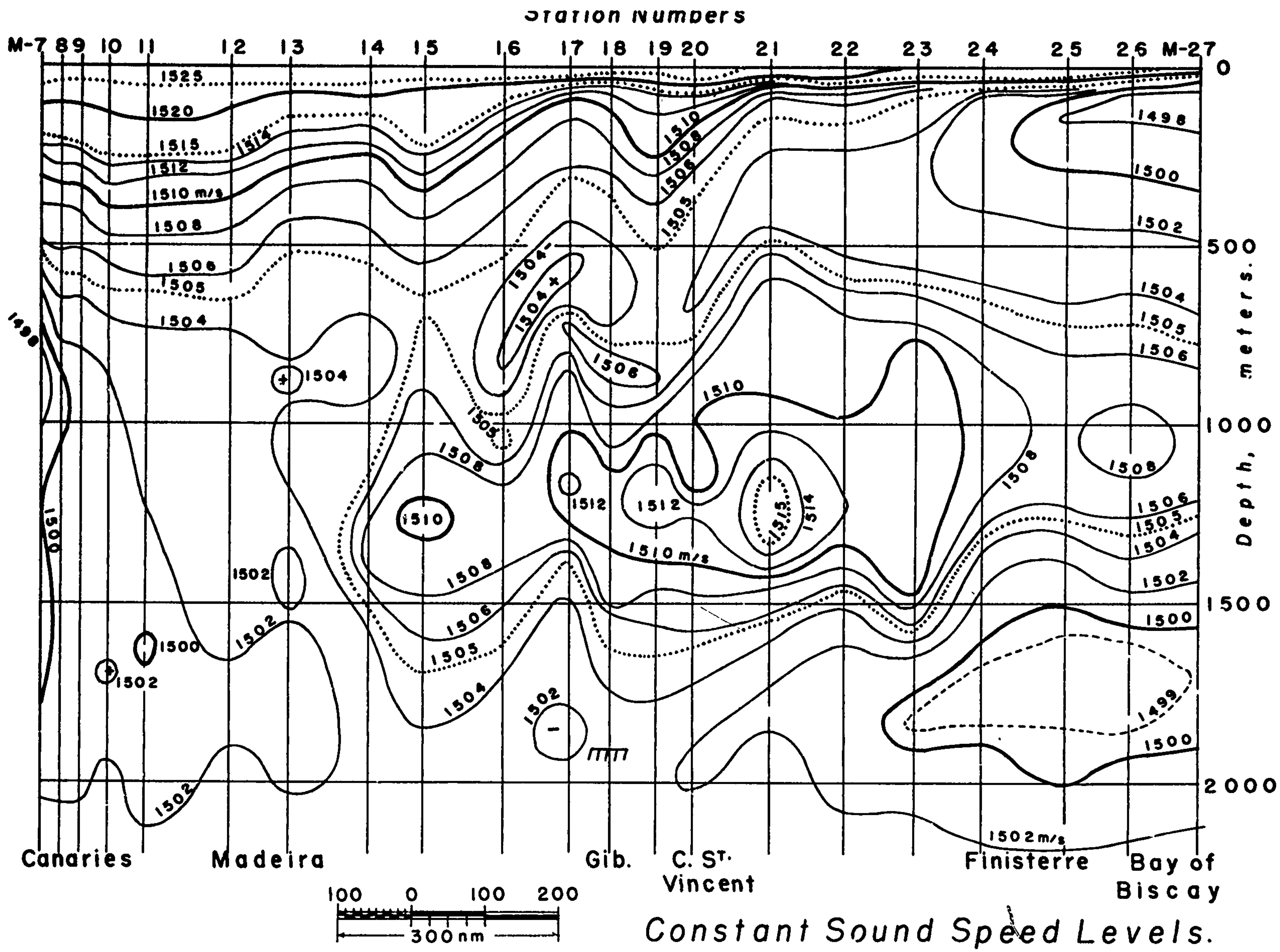
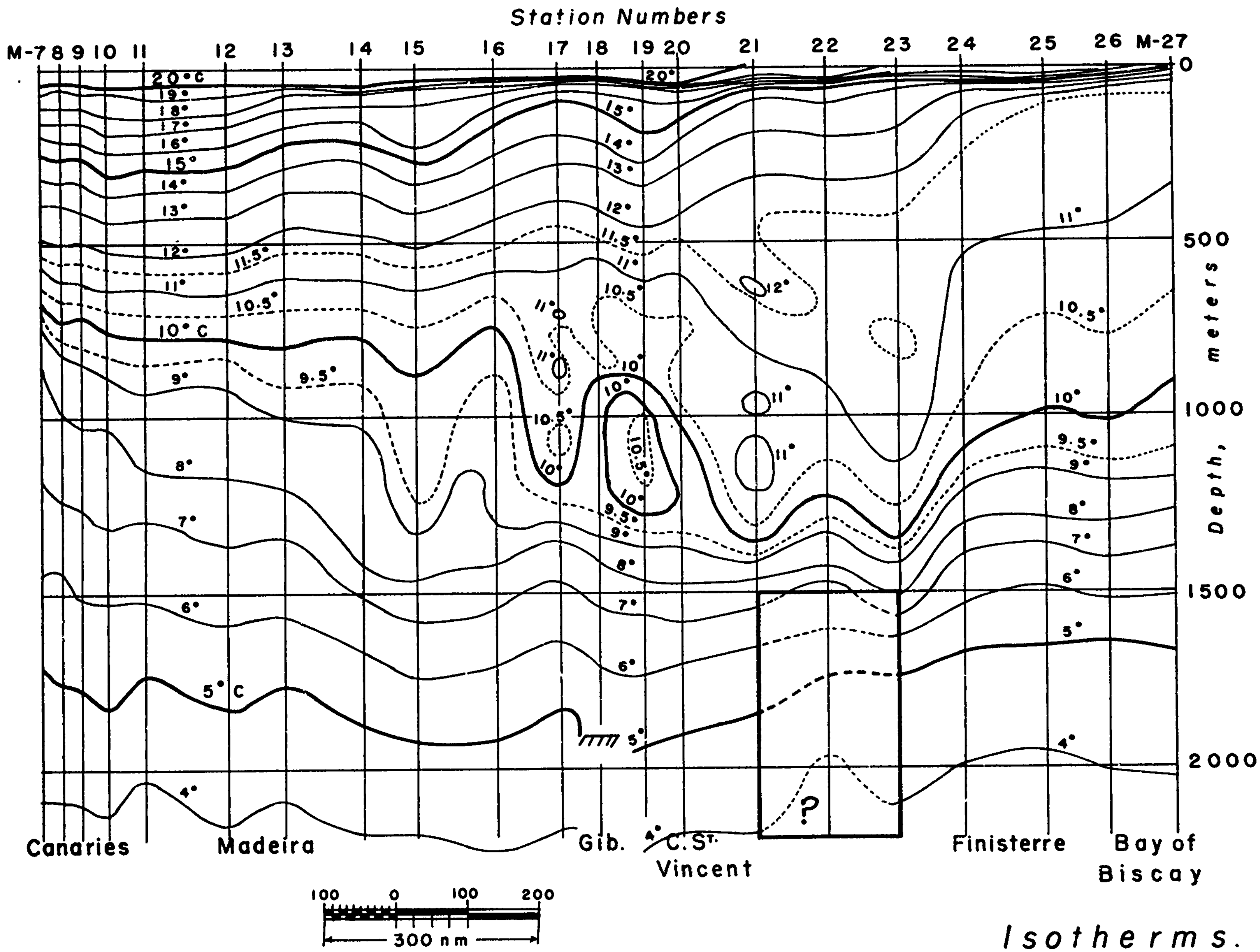


Fig. 59 *Sound Speed Section – Canaries to Bay of Biscay.*



Isotherms.

Fig. 60 Temperature Section - Canaries to Bay of Biscay.

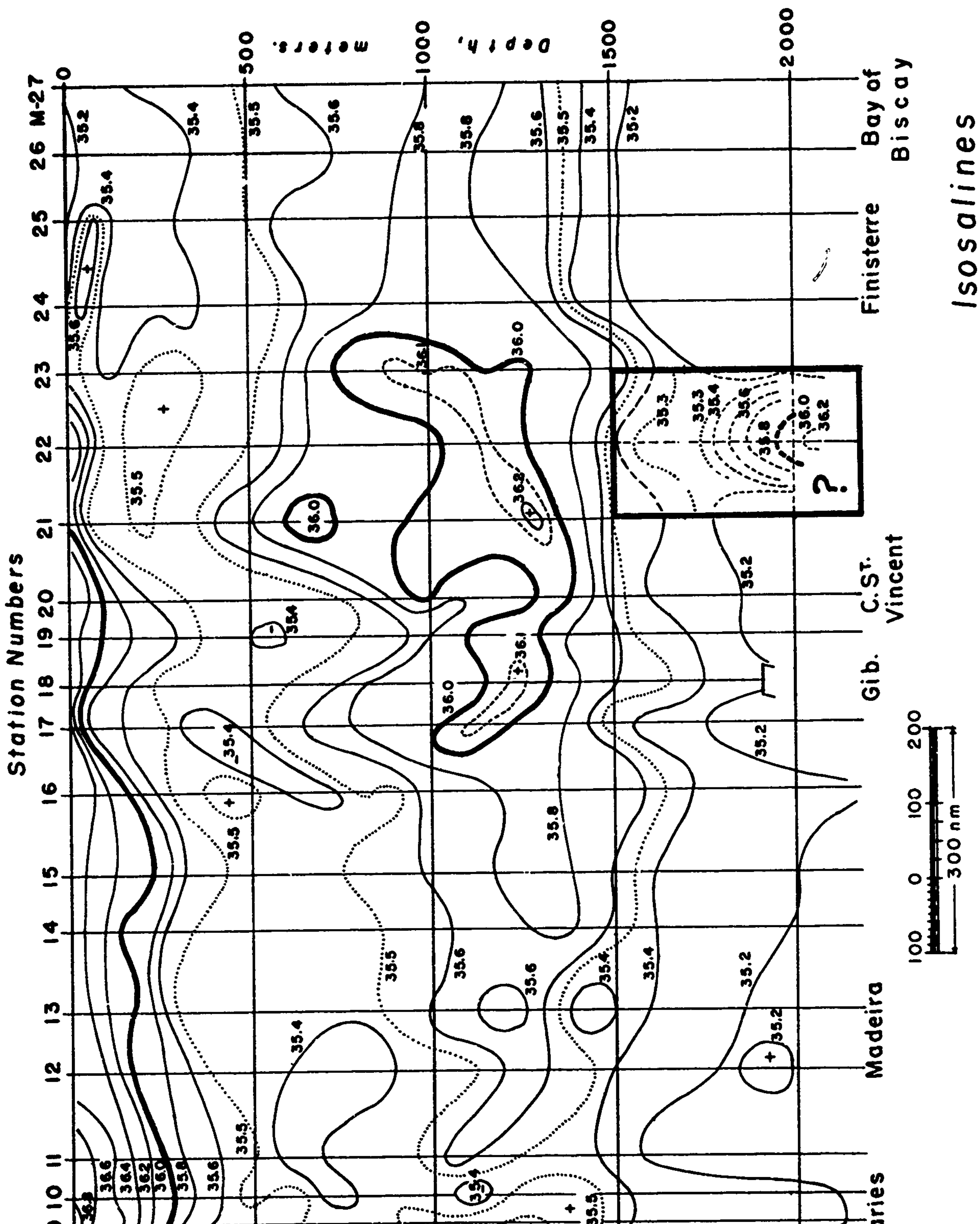


Fig. 61 Salinity Section - Canaries to Bay of Biscay

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13. ABSTRACT
Detailed, consecutive sound speed and temperature profiles to 2300 m depth, and profile envelopes for each station, are presented for 26 multi-profile stations: 5 in the Canary Islands; and a near-synoptic series of 21 on a track Canaries - Gibraltar - Bay of Biscay. Sound speed, temperature and salinity (calculated from sound speed, temperature and depth) cross sections for the Canaries - Bay of Biscay part are also presented. A discussion of the spreading of Mediterranean waters from Gibraltar, and the accompanying changes in the sound speed structure is included: 1) the spreading of the Mediterranean waters has an entirely different character in the two directions. Towards the southwest the Mediterranean water soon mixes with the surroundings. Off Madeira and in the Canaries mixing is complete, temperature decreases smoothly from the surface layer downwards, without a pronounced deep thermocline. The deep salinity maximum has disappeared. Occasional large cells of Mediterranean water reach this area without mixing: one such cell is described. Towards the north, the Mediterranean water moves to 42° N without appreciable mixing, where the main body seems to veer to the west, but a good part continues into the Bay of Biscay, retaining its identity between North Atlantic surface and deep waters. 2) The sound speed structure has a uniform trend from a flat, wide sound channel reaching from 1000 to 2000 m depth in the Canaries to a distinct two-channel structure further north, the two channels becoming more sharply defined and spreading apart in depth as one goes north.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Oceanography						
Underwater acoustics						
Sound Speed: consecutive, detailed profiles						
Sound Speed: envelopes of consecutive profiles						
Temperature: consecutive, detailed profiles						
Temperature: envelopes of consecutive profiles						
Canary Islands						
Gibraltar						
Bay of Biscay						
Sound speeds, Canaries - Bay of Biscay						
Temperatures, Canaries - Bay of Biscay						
Salinity, Canaries - Bay of Biscay						
Spreading of Mediterranean waters.						
Cells of water in the ocean.						

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