A SUMMARY OF OCEANOGRAPHIC DATA OBTAINED IN DEEP WATER IN THE STRAIT OF SICILY IN MAY 1970 (MILOCMED SURV 70)[†]

by

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ABSTRACT

Observations of temperature and salinity using a TSD profiling system were made down to 500 m in a deep water area southeast of Pantelleria Island in the Strait of Sicily in May, 1970. The usual two layer system was observed, consisting of upper Atlantic water flowing ESE over a WNW flow of high-salinity eastern Mediterranean "intermediate" water. The variability observed in both the space and time stations occurred mainly in the upper 180 m layer, where the strongest temperature and salinity gradients occur. At a 12-hour time-station less variability in the profiles of temperature was observed than appeared at either of two 45-km long six-station spatial sections made 6 days apart in the same area.

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INTRODUCTION

During May 1970, a series of acoustic tests and oceanographic surveys (MILOCMED 70, Ref. 1) was conducted in a relatively deep water area defined by a 15 n.mi by 25 n.mi (28 km by 46 km) rectangle centred about 25 n.mi (46 km) SSE of Pantelleria Island in the south central part of the Strait of Sicily [Fig. 1].

The so-called "deep water area" or (DWA) is situated over an elongated basin having a relatively flat bottom averaging 1100 m to 1200 m in depth [Ref. 2]. The basin is bordered on the northeast and southwest by the irregular sloping sides of the Strait of Sicily, which shoal within 10 km to 30 km to a 100 m to 200 m deep shelf-zone bounding both the Sicilian and Tunisian coasts.

The water in the area consists of two well-defined layers, a known characteristic of the Strait of Sicily [Ref. 3]. The upper layer, which is mostly Atlantic surface water, is described by Wüst [Ref. 4] as being 75 m thick, but manifestations of water from this layer can be observed to mix down to 150 m - 200 m depths. This water, having salinities ranging from 37.2‰ to 37.4‰, enters the Mediterranean sea through the Strait of Gibraltar, then moves eastward along the African coast and part of it flows ESE through the Strait of Sicily.

Underneath this surface layer the Mediterranean intermediate water [Ref. 4] flows WNW over the Sicilian sill. This intermediate water, which extends from depths of 180 m to 200 m down to 600 m, originates from convective sinking of cooled surface water in the Levantine basin and has a remarkably uniform salinity averaging 38.8‰.

Thus there is an exchange of water taking place across the Strait of Sicily similar to, but not as intense as, the exchange through the Strait of Gibraltar. The presence of the opposed two-layer flow of different water masses, together with the observed strong current shears and their related vertical mixing, renders this zone extremely complex and interesting.

Prior to, and shortly after, the MILOCMED 70 acoustic tests in the "deep water area", oceanographic observations were made in the form of temperature and salinity profiles (TSD stations) in an attempt to correlate the effect of the local oceanic environment with the results of the acoustic experiments. This report examines the variability in the temperature and salinity profiles obtained in the DWA.

1. TEMPERATURE AND SALINITY

A spatial section, consisting of six temperature salinity/depth (TSD) profiles and supplementary expendable bathythermograph (XBT) profiles, was made along the 25 n.mi (46 km) track [Fig. 1] in the DWA on 10 May 1970 (DWA I) and again on 16 May (DWA II). In addition, a time series consisting of twelve hourly measurements was made in the centre of the DWA between stations 3 and 4 [Fig. 1] during 16-17 May while the vessel was held within about a 400 metre diameter circle (successive radar fixes on several points on Pantelleria Island were used as checks).

The TSD lowerings were made to 500 m with a Bisset-Berman probe. The XBTs were taken to depths of 450 m to 500 m at all TSD stations of the spatial sections (DWA I and II) and also at two positions between the stations [Fig. 1]. The data were recorded as frequency analogue outputs on magnetic tape and also directly as voltage analogue curves on an X-YY plotter, the latter giving continuous traces of temperature and salinity as a function of depth. The data reported here have been taken direct from the analogue plots.

Field calibrations of the TSD system were made by attaching two Nansen bottles, each with a pair of reversing thermometers, immediately above the TSD probe and making direct comparisons of the two sets of temperature and salinity data. In the two observations made, the TSD temperatures were identical with those of the reversing thermometers within the prescribed accuracy of the TSD system (i.e. about ±0.02°C). The salinity values of the TSD plots were consistently 0.11‰ too high. The proper corrections have therefore been made on all the salinity curves presented.

2. THERMISTOR CHAIN RECORD

An added set of environmental data is provided by an 18-hour thermistor chain record made during 18-19 May, which gives a description of the relatively rapid temperature fluctuations in the surface layer. These observations were obtained from the MARIA PAOLINA while at anchor some 43 n.mi (80 km) north of the DWA (280 m water depth) in the centre of the sill area of the Strait of Sicily [Fig. 1]. The chain, with a 20 kg weight attached, was suspended vertically from the vessel. This record consists of temperatures registered at 3-minute intervals at 18 depths between 1 m and 58 m. It is felt that this record, although not made in the DWA and made in relatively shallow water, is still representative of the high-frequency temperature fluctuations occurring in the Strait during this period.

3. RESULTS

3.1 General

The TSD profiles of salinity and temperature for the two spatial and one time-series stations in the DWA are displayed in Figs. 2, 3, and 4 respectively.

3.2 Temperature

The temperature profiles indicate clearly the two water layers. Between the surface and 150 m to 180 m is a "noisy" region that displays fluctuations both in space and time and contains many inflections and steep gradients and is, in general, very complex. Both the space and time series traces [Figs. 2a, 3a, 4a] indicate what might be considered three sublayers within this upper region, namely:

(a) The upper layer from the surface down to 30 m to 40 m reflects the effects of local surface heating and cooling and subsequent vertical mixing. These parameters are controlled mostly by the amount of solar radiaton and wind mixing that occurred during the few days preceding the observations. We note that between 10 and 16 May the surface temperature of this layer increased by 1.0°C to 1.5°C.

In the first section, DWA I, no surface mixed layer is seen and there is much change in the mean vertical temperature gradient from station to station. In DWA II a 5 m to 10 m thick surface isothermal layer occurs at station 1 and progressively deepens with successive stations. This mixed layer is seen again in the time series and further develops, reaching down to 30 m to 35 m, by station 12. We note that the wind blew with between force 4 and 5 throughout the 16, 17 and 18 May, explaining the development of the mixed layer.

(b) The next layer extends down to about 100 m and contains a strong negative gradient averaging 0.1°C/m. This layer reflects the gross spring heating in which the seasonal thermocline is beginning to develop.

(c) Between 100 m and 180 m in all the profiles there was a relatively strong inversion (of about 1°C). The shape of the temperature profile in this layer varied from station to station in both the DWA I and DWA II series. Many more fluctuations and discontinuities occur in this layer in the DWA II series than in the DWA I series.

Below the bottom of the temperature inversion (150 m to 180 m) the temperature slowly decreases with depth to and beyond 500 m. The water below 200 m is the Levantine middle water and is very well mixed, serving as a boundary that reflects the strong spatial and temporal variability of the water layers above. The temperatures recorded at 500 m show a maximum range of 0.12°C.

The time series of temperature profiles [Fig. 4] show variations that are not as large as those of the spatial series [Figs. 2a and 3a]. There is, however, the persistent variability in the inversion layer, where the fluctuations at a particular depth may range from 0.2°C to 0.5°C. Maxima and minima spikes are seen to appear, change shape, and disappear with time.

The XBT profiles [Figs. 5a and 5b] show similar temperature variations in both space and time but unfortunately have relatively small gain of the temperature signal on the strip chart output.

3.3 Salinity

The salinity profiles [Figs. 2b, 3b and 4b] show, even better than do the temperature profiles, the presence of two major layers. The surface salinity ranges from about 37.20‰ to 37.63‰. Below 30 m to 50 m, on the average, the salinity increases steadily with depth, reaching 38.70‰ at 170 m to 190 m. Beyond this depth — which coincides with the Levantine middle-water, temperature layer — the water is quasi-isohaline, increasing in salinity only slightly to 38.75‰ at 500 m. This value is slightly less than the 38.80‰ value given by Wüst [Ref. 4], probably because a higher concentration of Atlantic water is mixed with the Levantine water in the Strait than in the water to the east.

It will be noticed that wherever strong temperature gradients occur, particularly at 10 m to 30 m, there also appear sharp negative-salinity spikes. These inflections are falsely produced by the TSD system as it passes through the temperature gradients. Coupled with the salinity sensor is a temperature compensation circuit that is intended to offset the bias caused by a temperature change in the salinity-sensing conductivity cell. Unfortunately, the response time of the compensating circuit is poorly matched with that of the temperature sensor and hence, when the TSD is lowered at high speed through normal temperature gradients or at normal speed (say 1 m/s) through relatively strong gradients, these false negative-salinity spikes are produced. (with the digital

TSD data the spikes can, in a quite arbitrary fashion, be corrected or filtered out, but this requires an accurate knowledge of the lowering speeds and of the cell and circuit parameters).

3.4 Observation of Fine Temperature Structure with the Thermistor Chain

The data presented so far were taken at intervals of not less than one hour. The 18-hour thermistor chain record made north of the DWA [Fig. 1] on 18 May allows some higher frequency temperature variability to be observed than is possible with the TSD time-series data of Fig. 4.

Figure 6 shows the time-series records of 360 points for each probe at the indicated depths. Between the surface and 11 m to 13 m there is a mixed layer and only small changes occur in the temperature. Between 13 m and 48 m, in the presence of a stronger gradient, there are fluctuations of up to one degree. At 38 m, rapid changes occur, with variations of up to 0.7°C within a 5-minute interval. There appear to be many thermal fluctuations of the order of one hour.

The mean values and the variances (σ_T^2) recorded in Table 1 permit the intensity of variability of the temperature fluctuations to be estimated. As usual, the variability is seen to be strongly related to the depths at which the mean gradient is the largest. These fluctuations might have been caused by the ship swinging at anchor and changing the tension of the chain, thereby causing the thermistors to rise and fall through the temperature gradient. However, with the prevailing light winds (averaging 2 m/s to 3 m/s) and a sea state of from 1 to 2, the ship's swinging and rotational motion on the anchor was observed on the gyrocompass to be small. Also, the angle of the chain was not seen to exceed 4° to 5° and was generally observed to be vertical. It appears therefore that the changes observed are caused by vertical translation of the isotherms and not of the instruments.

4. DISCUSSION

The main difficulty of sampling oceanographic parameters in space or time is that the results of each mode of sampling are unavoidably functions of both space and time. Thus, spatial samples obtained from a ship moving relatively slowly between stations are obviously spaced also in time. Equally, time samples collected at "one location" from a ship or loosely-moored buoy contain a similar bias, since the platforms are moving in response to winds and currents, for which full compensation cannot be made. Thus, comparisons of space and time data are informative to the extent that their observational procedures can approach the ideal situation, i.e. where sampling is purely in space (at one instant of time) or purely in time (at one point in space). The data presented here were taken under conditions that only crudely approximate the above criteria for ideal sampling.

For a direct comparison of the temperature and salinity variability in the DWA, the profiles for each of the space and time-series TSD observations were superimposed. An envelope was then drawn around the superimposed profiles to indicate the range of variability as a function of depth [Fig. 7]. The area of the envelope divided by the depth gives the average width of the envelope over the observed water column. This value, which we term the mean variability range (signified by A), may be written as

$$A = \frac{1}{D} \int_{0}^{-D} T_{MX}(z)\, dz - \int_{0}^{-D} T_{MN}(z) dz \qquad \text{[Eq. 1]}$$

where -D is the depth of the series of profiles, i.e. 500 m, and T_{MX}, T_{MN} are the maximum and minimum boundary profiles, respectively. The vertical coordinate is measured positively upward.

Values for the mean variability range A_T and A_S for temperature and salinity respectively are given in Fig. 7.

(In comparing such a parameter derived from groups of profiles it is important that the sets of data be comparable, i.e. similar numbers of profiles taken over known intervals of time or space with the same or similar instruments).

Comparison of the range of temperature variabilities for DWA I and DWA II (the two envelopes on the left of Fig. 7a) shows that a gross change occurred in the shape of the profiles between the two periods, particularly above 200 m. The greatest change is noted in the upper 30 m to 40 m, where an increase of temperature of from 0.5°C to 1.8°C occurred during the six-day interval. The variability of the DWA I profiles between about 40 m and 100 m is greater than that of the DWA II profiles. On the other hand they show more variability from 100 m to 160 m in DWA II than in DWA I.

Turning now to the time-series envelope (the right-hand envelope of Fig. 7a), it is seen that its width is consistently smaller than either of the space-series envelopes, particularly from 100 m to 300 m depth. The times required for sampling DWA I and DWA II were 5.55 hours and 4.78 hours respectively. The time-series variation indicates that some of the changes found in the spatial profiles can be caused by pure time changes at a point. However, since the A_T is much less for the 11-hours time series than it is for either of the 5.6 hours or 4.8 hours space stations we may conclude that most of the variability in the spatial sections are associated with actual horizontal temperature gradients, which apparently are in quasi-steady state at least over the time scales of the order of 5 to 10 hours.

The salinity envelopes [Fig. 7b] present a similar, although not identical, picture of the time/space variations to that of the temperature envelopes. Section DWA I is much more variable than DWA II. In the upper 150 m layer the horizontal width of the envelope for DWA I is 2.03 times that for DWA II and at 100 m the range for DWA I exceeds 1‰. The values show that, as with temperature, the time variability is in general smaller than the space variability. However, the large discrepancy between DWA I and DWA II may indicate that a gross change occurred in the salinity structure during the six days between DWA I and DWA II. (Note that the curves used here to estimate the variability contain the negative-bias spikes caused by the strong temperature gradients. The error introduced should be small, however, since the spikes add only a few percent of the total area of the envelope used to calculate mean variability amplitude values).

The horizontal variability occurrring over the six space stations (DWA I and DWA II) is shown in Fig. 8 by plotting the temperatures and salinities obtained at 4 m, 40 m, and 500 m. Clearly, the changes at 500 m both in space (i.e., along the six-station section) and time (i.e. between observations DWA I and DWA II) are much smaller than those occurrring at 40 m and 4 m depths. The gross heating in the surface layer between 10 and 16 May is evident from the differences in the 4-m temperatures (DWA I and DWA II). Otherwise, the spatial changes of the 4-m temperatures and salinities tend to be obscure since they were grossly affected by diurnal heating and wind mixing that occurred within the 0800-1430 sampling period (which was about the same for both 10 and 16 May). The 40 m temperatures are strongly variable in time (between DWA I and DWA II and in space (between stations 1 and 6).

The variations in temperature and salinity from station to station seeem to occur in similar ways at 4 m and 40 m. This is especially noticeable in the DWA I data. For salinity, which is a somewhat more conservative property than temperature, the differences between the 4 m and 40 m depths seem to remain roughly the same (i.e. about 0.15‰ to 0.20‰) even though the actual values differ considerably between stations 1 and 6.

It should be expected that there would be strong variability in the temperature and salinity distributions in the upper 200 m of the Strait of Sicily, where one distinct water mass overflows another.

Current shears must exist and mixing will therefore occur across the strong gradients of salinity and temperature observed in Figs. 2 and 3. Unfortunately, no current observations were made in the DWA. However, a 12-day record was made with several current-meter buoys moored in the sill area between Cape Bon and Trapani [Fig. 1] during this sampling period. These data — to be reported later — should indicate the degree of advection and, together with the values of horizontal temperature gradients in the area, can provide a better idea of the expected space and time variability.

Ziegenbein [Refs. 6 and 7] recorded short internal waves in the form of large-amplitude vertical displacements of isotherms (apparently tidally driven) in the sill area of the Strait of Gibraltar. These waves, however, appeared to be strongly damped once initially produced. A cursory look at the time-series profiles of TSD and XBT data reveals no obvious vertical displacements of isotherms or isohalines that might be associated with internal waves. For one reason the tidal currents in the Sicily area are somewhat weaker than at Gibraltar, hence perturbations generated in the sill area may have decayed so much as to be undetectable in the DWA 90 km to 100 km to the south. Also, Ziegenbein's experiments in Gibraltar were made in September, when the seasonal thermocline was stronger than that present during the May~~h~~ observations in the Strait of Sicily. There might also be oscillatory or transient fluctuations at frequencies above, say, one cycle per hour or below one cycle per day that would not be observed because of the choice of sampling intervals.

CONCLUSIONS

The TSD observations made in both space and time in the "deep water area" SEE of Pantelleria Island in the Strait of Sicily suggest the following:

(a) The water column is essentially composed of two layers. The upper one, between the surface and 180 m to 200 m, contains strong temperature and salinity gradients throughout. In this layer the temperature profile is highly variable and contains one or more strong inversions, while the salinity increases from the surface more monotonically, although not smoothly. The variability of both parameters at a given depth is found to be relatively large in both the space and time scales sampled, but more pronounced in the former.

The layer below 180 m to 200 m is the well-mixed intermediate water. Between 200 m and 500 m the temperature decreases by only about 0.2°C and the salinity increases by only about 0.03‰.

The strong variability in the upper layer is associated both with the surface meteorological effects and the complex mixing across the gradients, which would be associated with what are probably strong time-variable current shears generated between the two gross layers moving in opposite directions.

(b) A six-station, 45-km space section of TSD casts, which was repeated after six days in the DWA (roughly five hours being required for each section), showed larger spatial changes in temperature and salinity then were observed in an eleven-hour, 12-profile time-series station made in the middle of the DWA (after completion of the second space section). It appears, at least over the characteristic length of 45 km, that during a given period (of the order of 12 to 24 hours) in the DWA the spatial variations of temperature, salinity (and hence sound velocity) dominate over time (Eulerian) variations of these parameters at one location. The brief time series shows no clear oscillatory vertical displacements of isolines but more of a random variation at different depths at different times. Thus internal wave motions having a band of periods ranging from one or two hours up to half a day do not appear to contribute significantly to the changes observed in temperature and salinity.

It is concluded that the spatial changes observed are mostly caused by the presence of mean of slowly-varying horizontal gradients and the smaller time changes are mostly caused by weak advection of gradients contained within the strongly layered structure that occurs within the upper 200 m.

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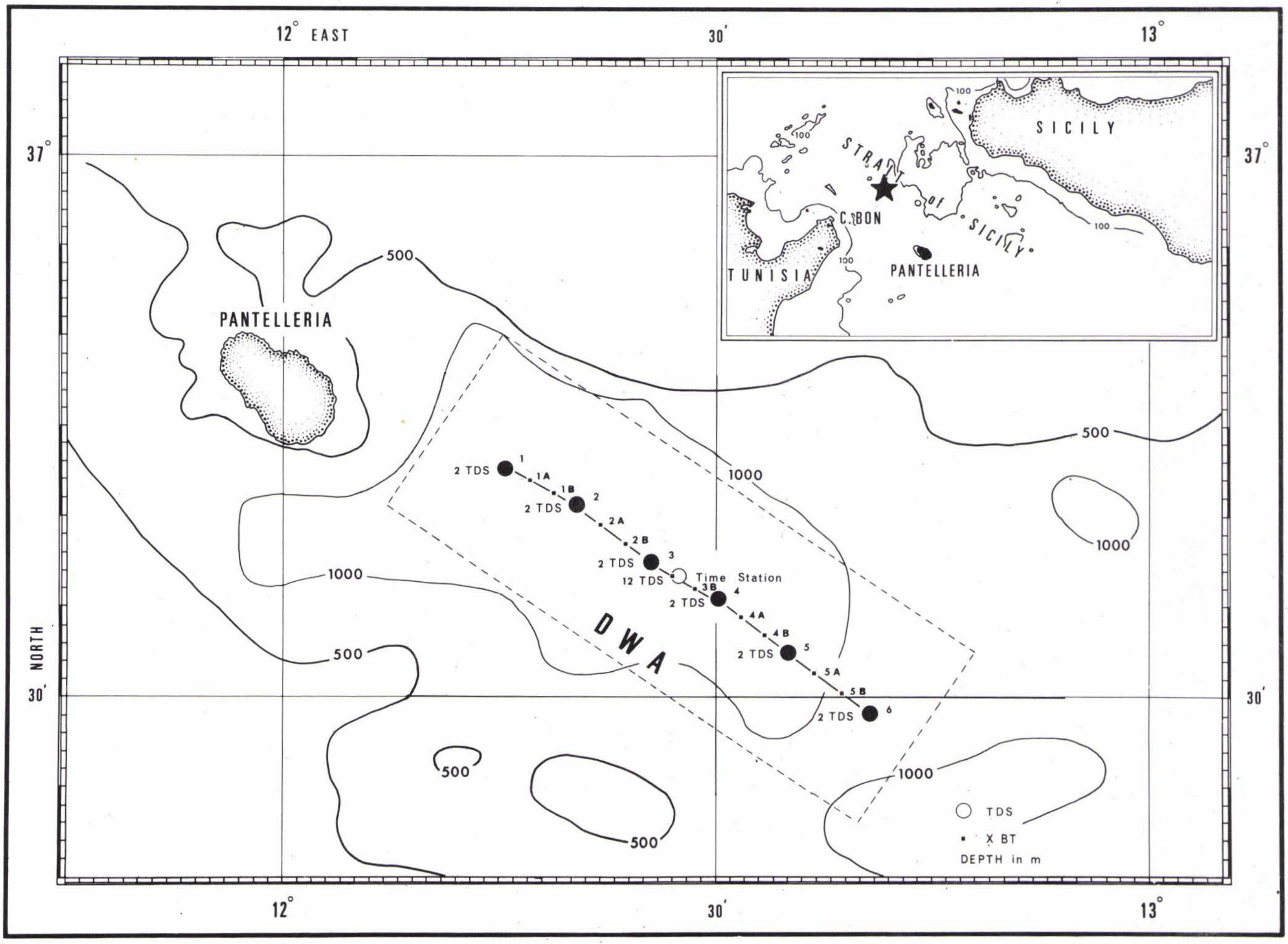


FIG. 1 MILOCMEDSURV 70 DEEP WATER AREA. On 10 May and 16 May TDS and XBT measurements were made at each of the six stations, XBT measurements were also made at intermediate points. On 16–17 May a time-series of TDS and XBT measurements was made in the centre of the area. Thermistor chain measurements were made on 18–19 May at the point marked on the inset with a star.

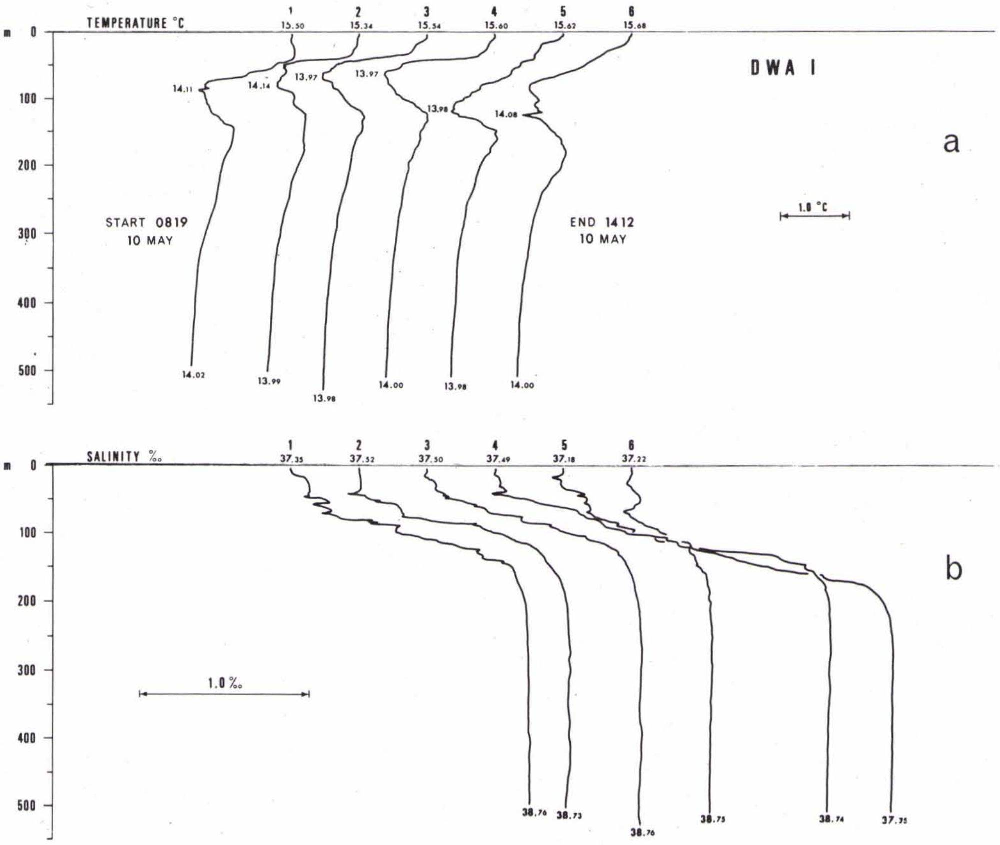


FIG. 2 TDS SPATIAL SECTION OF THE DEEP WATER AREA, 10 MAY (DWA I)

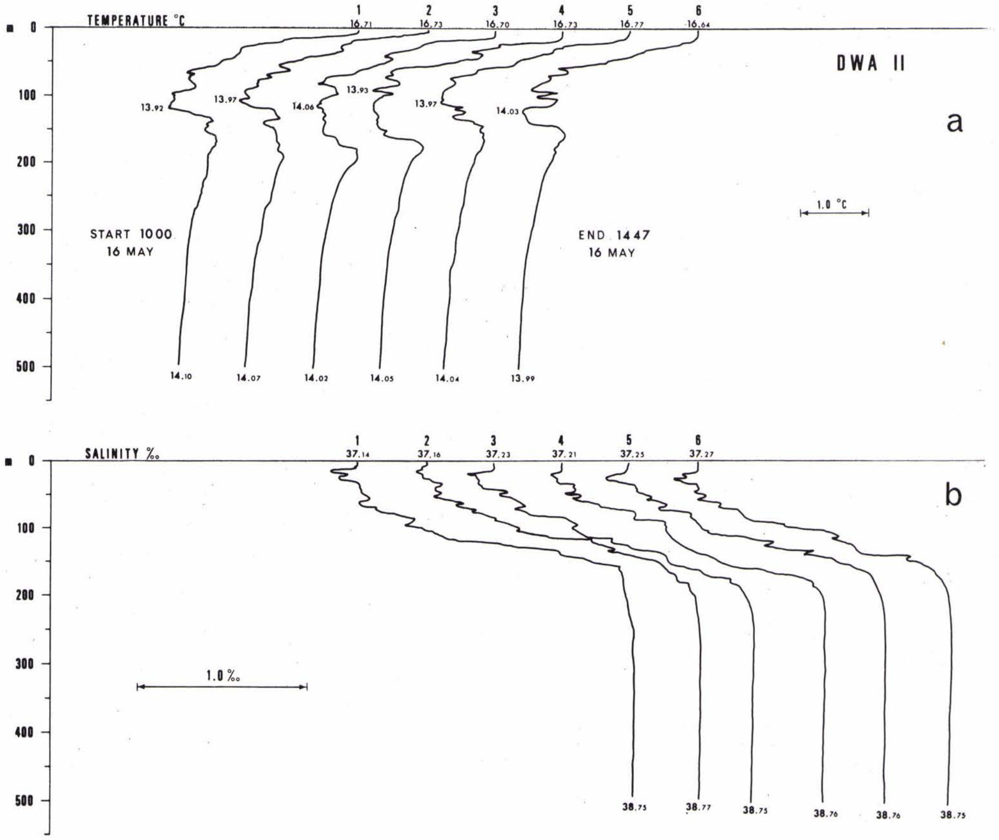


FIG. 3 TDS SPATIAL SECTION OF THE DEEP WATER AREA, 16 MAY (DWA II)

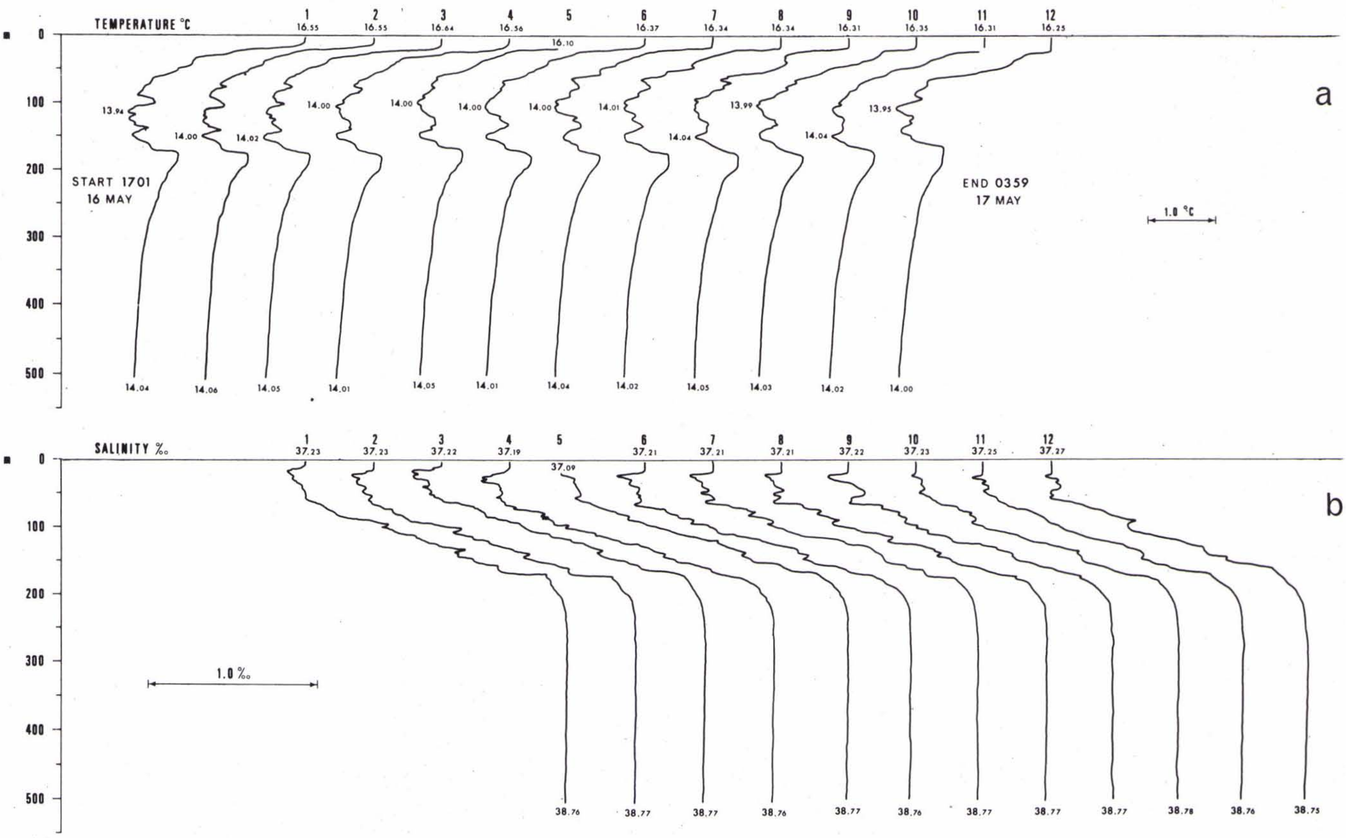
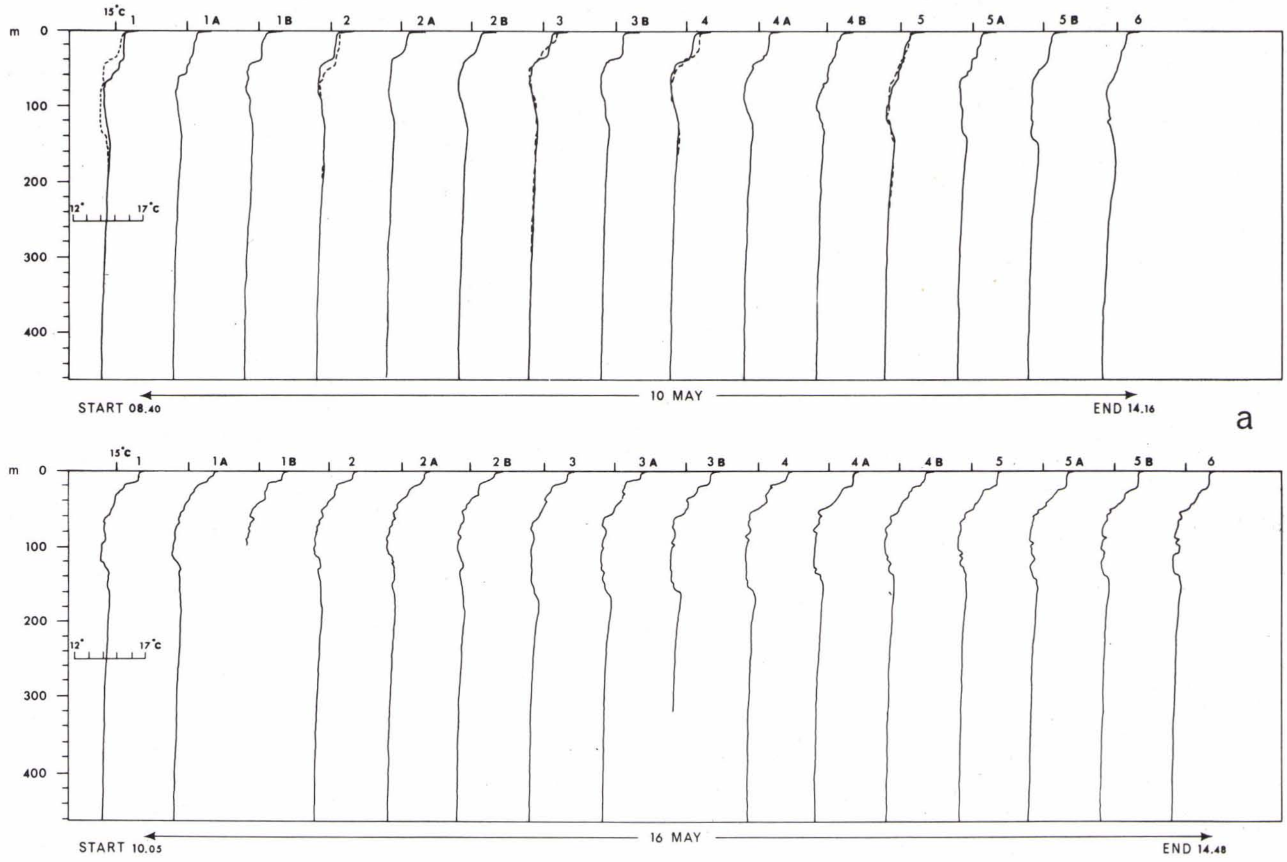


FIG. 4 TDS TIME–SERIES AT CENTRE OF DEEP WATER AREA, 16–17 MAY (TS–1 to TS–12)

SPACE SECTION



TIME SERIES

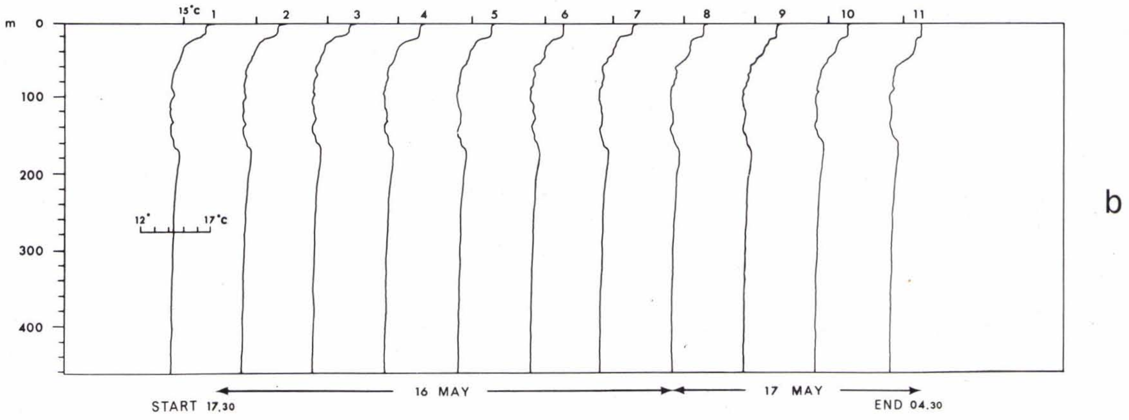


FIG. 5 XBT MEASUREMENTS IN THE DEEP WATER AREA

TABLE 1

STATISTICS OF THERMISTOR CHAIN DATA

Between times	18 May 1548	19 May 0524	N = 270
(m)	Mean ($^\circ$C)	Variance ($^\circ$C)^2	σ_T ($^\circ$C)
1.00	16.30	0.00288	0.0537
2.00	16.28	0.00299	0.0547
3.00	16.28	0.00297	0.0545
4.00	16.30	0.00298	0.0546
5.00	16.30	0.00288	0.0537
6.00	16.28	0.00280	0.0529
7.00	16.26	0.00286	0.0535
8.00	16.23	0.00303	0.0550
9.00	16.27	0.00261	0.0511
10.00	16.25	0.00327	0.0572
11.00	16.21	0.00449	0.0670
13.00	16.19	0.00670	0.0819
18.00	16.09	0.01158	0.1076
23.00	15.96	0.01401	0.1184
28.00	15.77	0.01636	0.1279
38.00	15.22	0.06240	0.2498
48.00	14.72	0.03235	0.1799
58.00	14.44	0.00889	0.0943

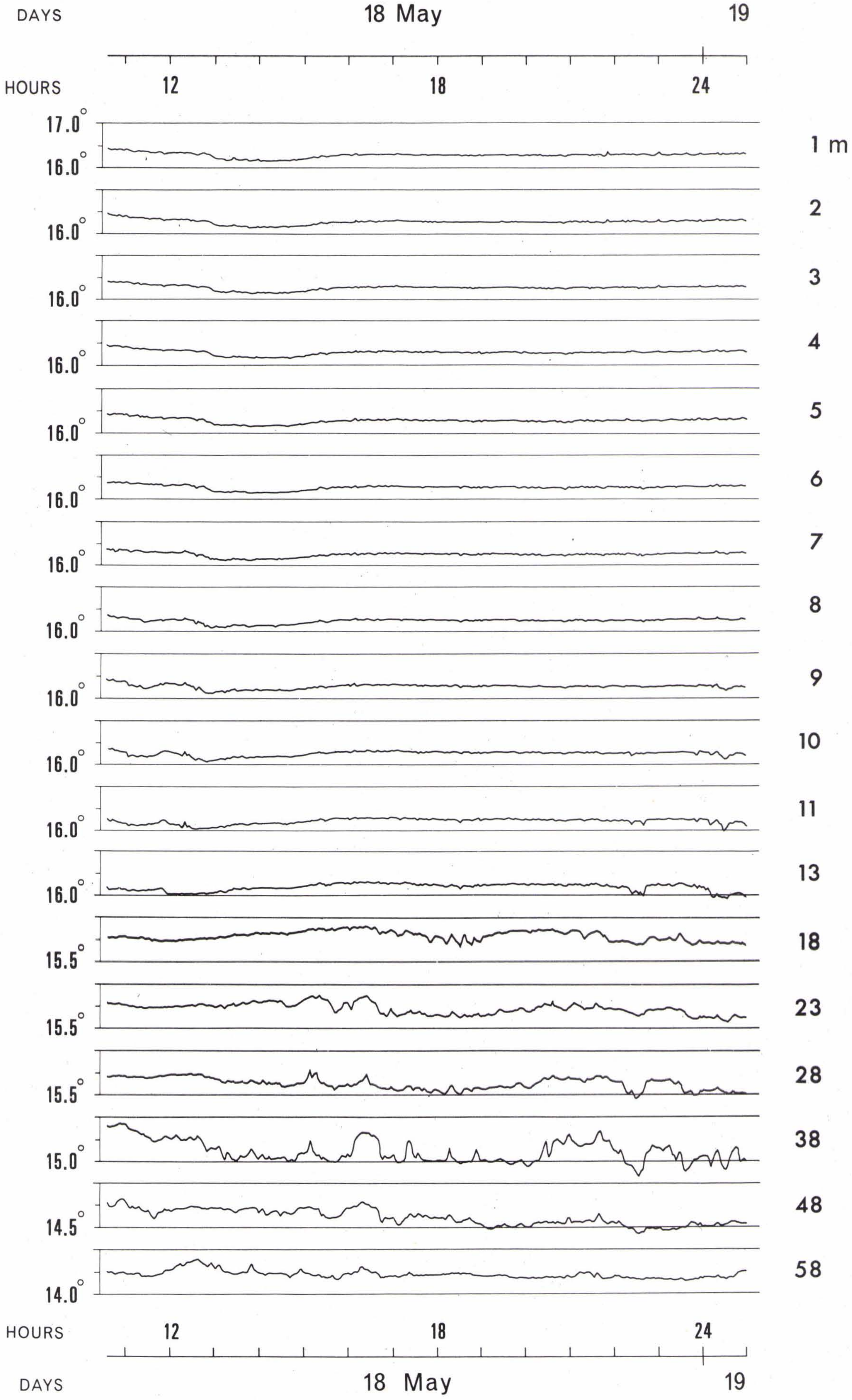
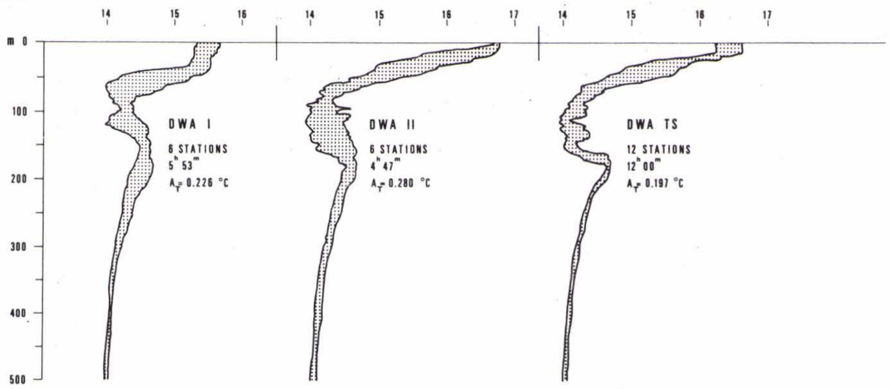


FIG. 6 THERMISTOR CHAIN MEASUREMENTS OUTSIDE THE DEEP WATER AREA (see Fig. 1 for position) 18–19 MAY

(a) TEMPERATURE °C



(b) SALINITY ‰

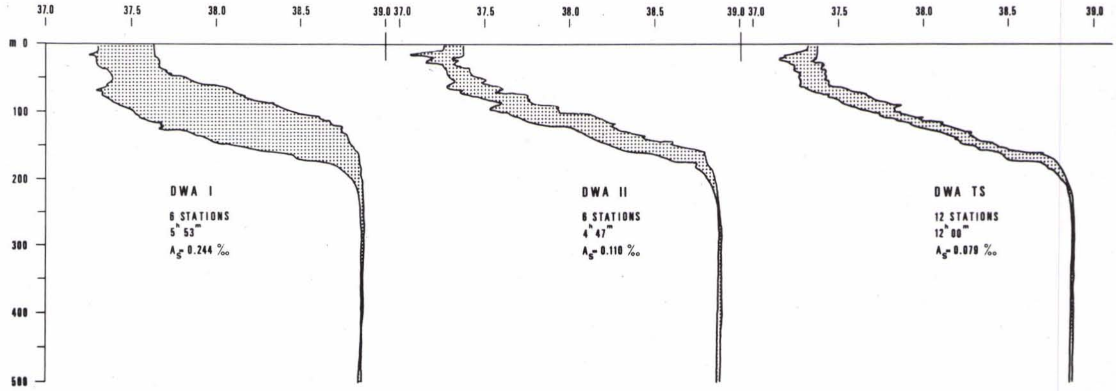


FIG. 7 RANGES OF TEMPERATURES AND SALINITIES RECORDED BY TDS IN THE DEEP WATER AREA

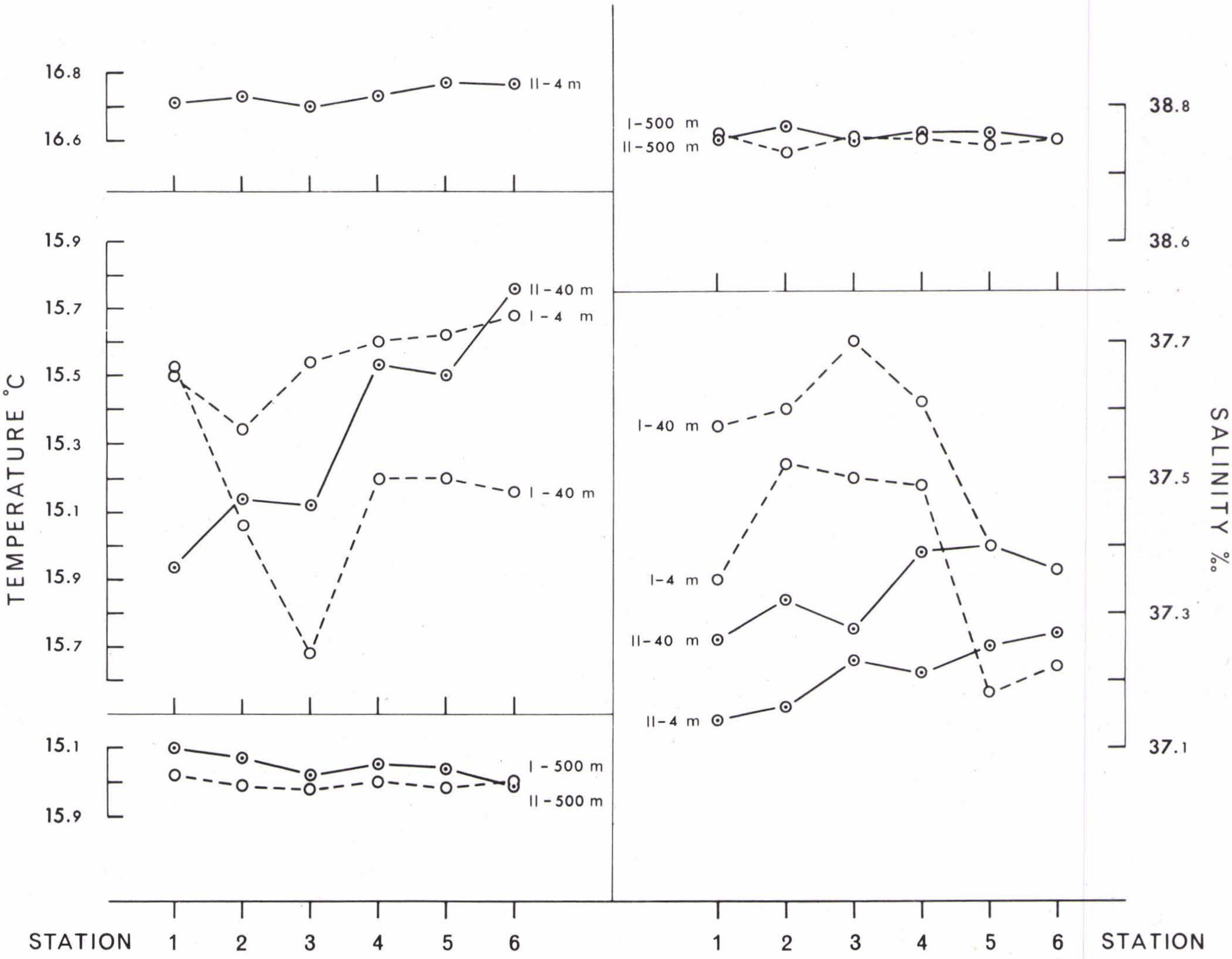


FIG. 8 HORIZONTAL CHANGES IN TEMPERATURES AND SALINITIES AT 4 m, 40 m and 500 m
Continuous lines refer to 10 May (DWA I), Dashed lines refer to 16 May (DWA II)