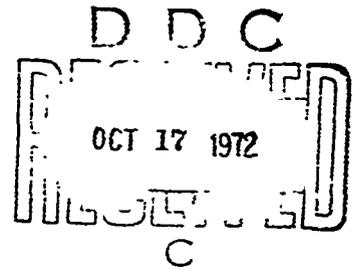


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Current Regime of the MALTESE Oceanic Frontal Zone

LCDR RALPH R. MILLER III
Program Officer for Oceanography



6 September 1972

NAVAL UNDERWATER SYSTEMS CENTER

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The "MALTESE" oceanic frontal zone lies due east of Malta in the Mediterranean in the region surrounding 36°N, 17°E. This report presents an analysis of 48 expendable bathythermograph (XBT) traces from the MALTESE frontal zone taken between 18 and 24 November 1971 (IOMED 71). Surface water moving eastward through the Africa-Malta straits and warmed to more than 20.0°C formed a distinct water mass above the thermocline in the study area. Mixing of this water with Ionian Surface Water formed complex frontal zones. These zones were collectively identified as the MALTESE oceanic frontal zone, which was easily traced with thermal probes. The density of this surface water was increased by evaporation and by cooling in the Levantine Basin east of the study area, whereupon this water sank to an equal density level below the thermocline. This Levantine Intermediate Water (LIW) then flowed westward through the study area in the form of large masses of 14.5°C water, between 60 and 850 m, toward an eventual outlet in the Malta-Sicily straits.

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ABSTRACT

The "MALTESE" oceanic frontal zone lies due east of Malta in the Mediterranean in the region surrounding 36°N, 17°E. This report presents an analysis of 48 expendable bathythermograph (XBT) traces from the MALTESE frontal zone taken between 18 and 24 November 1971 (IOMED 71). Surface water moving eastward through the Africa-Malta straits and warmed to more than 20.0°C formed a distinct water mass above the thermocline in the study area. Mixing of this water with Ionian Surface Water formed complex frontal zones. These zones were collectively identified as the MALTESE oceanic frontal zone, which was easily traced with thermal probes. The density of this surface water was increased by evaporation and by cooling in the Levantine Basin east of the study area, whereupon this water sank to an equal density level below the thermocline. This Levantine Intermediate Water (LIW) then flowed westward through the study area in the form of large masses of 14.5°C water, between 60 and 350 m, toward an eventual outlet in the Malta-Sicily straits.

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CURRENT REGIME OF THE MALTESE* OCEANIC FRONTAL ZONE

INTRODUCTION

The MALTESE oceanic frontal zone lies due east of Malta in the Mediterranean in the region surrounding 36°N , 17°E (figure 1). During November 1971, the Office of Naval Research sponsored a multilaboratory investigative effort called the Ionian-Mediterranean Exercise (IOMED 71), which was to determine the environmental characteristics of this area. The USNS SANDS (T-AGOK-6), sailing for the Naval Underwater Systems Center (NUSC), collected 48 Digitized Expendable Bathythermograph (DXBT) traces (appendix A) during IOMED 71 (see figure 2 for track of SANDS). These digitized data were analyzed to determine current and thermal properties of the Ionian Basin above 800 m at the MALTESE front. Results of that analysis are summarized herein. Oceanography of the IOMED region has been discussed by other investigators and their results are compared with present data. In general, agreement was found with the gross features of the current regime as previously described in the literature. Previous workers suggested that the waters moving eastward over the Africa-Malta strait are found above the thermocline. The area of mixing of these waters with the Ionian Sea surface waters has been termed the MALTESE oceanic front.

Johannessen et al.¹ suggest that the Levantine Intermediate Water (LIW) moving westward below the thermocline is seeking an outlet to the west through the Malta-Sicily strait. Large troughs of water displaying the characteristics of LIW have been noted in the literature and in this study.

*So named by Johannessen, Goid, and Smallemberger (reference 1).

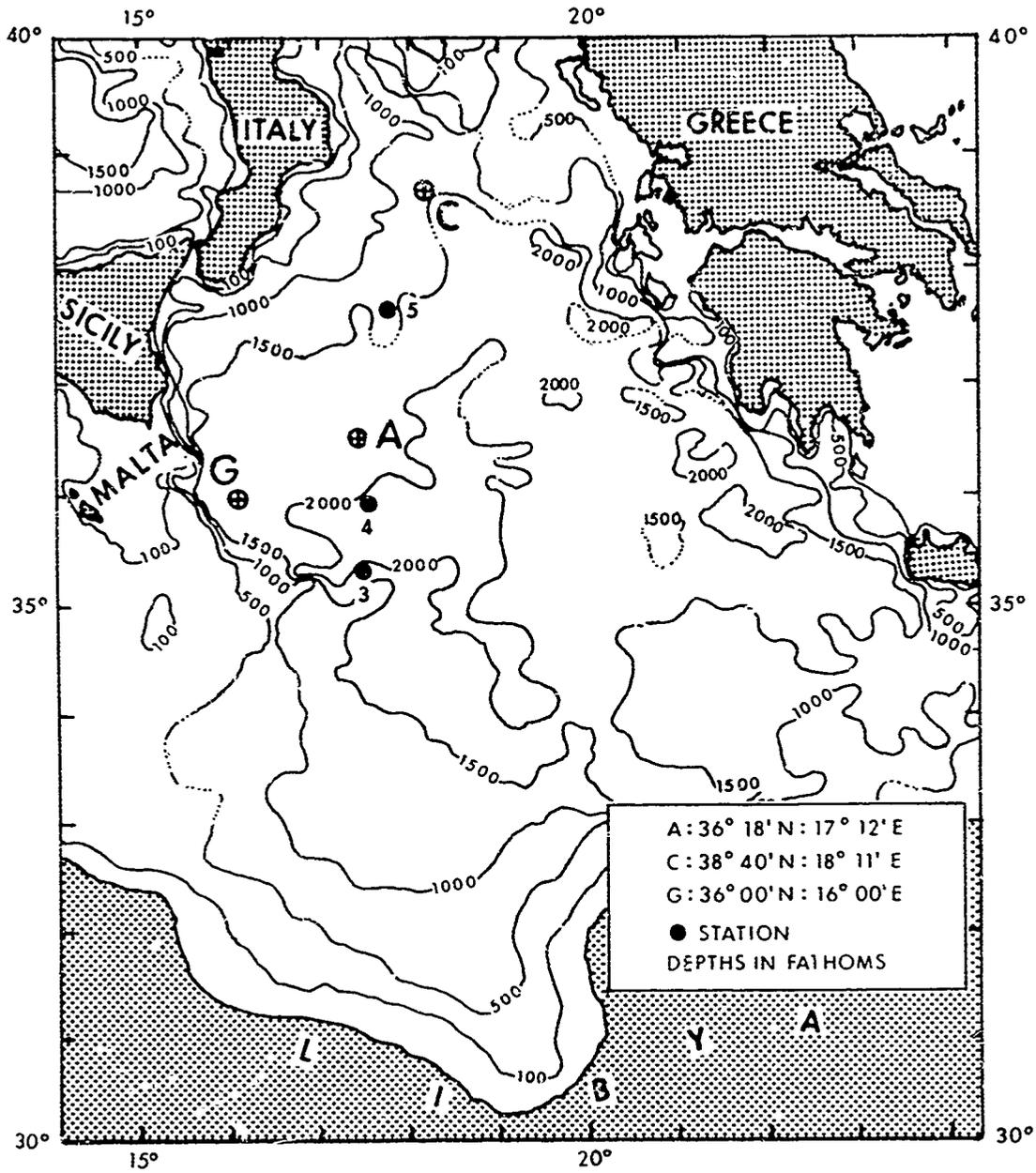


Figure 1. IOMED 71 Area Chart

BACKGROUND

In December 1970, Johannessen et al.¹ towed a thermistor string in the general area of IOMED and took salinity-temperature-depth (STD) stations at discrete locations. From the analysis of their data they inferred the existence of a thermal front lying approximately north-south from 36°N , 17°E to the south (figure 3), which they called the MALTESE front. Forty-five thermistors, towed from the surface to 225 m depth, were sampled every 10 sec. Consecutive readings were averaged to give the time average of the temperature over 275 m of horizontal travel. Their analysis showed that the eastern side of the front was characterized by a downward sloping wedge of water from east to west whose upper temperature was approximately 18.25°C . The western side of the front

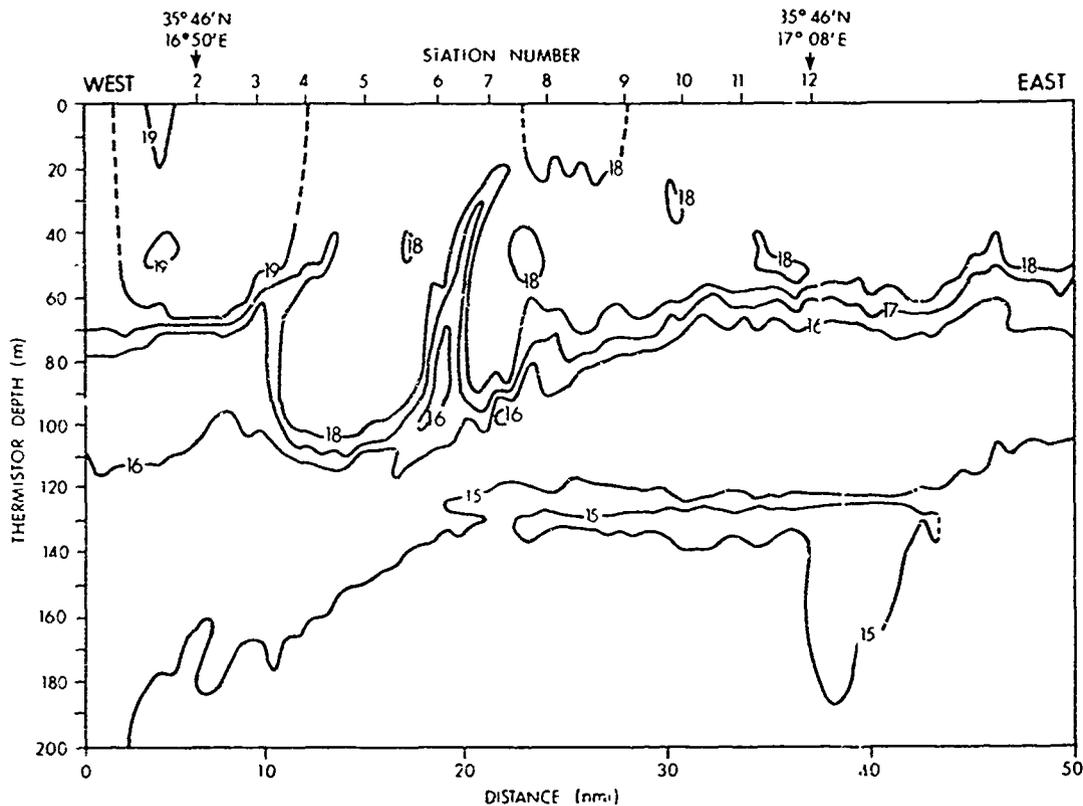


Figure 3. Cross Section of MALTESE Front
(From Johannessen et al. : private communication)

was characterized by a constant-depth isothermal layer at 18.96°C down to 100 m. Spikes of colder (eastern) water had intruded into this isothermal region and may have represented vertical frontal turbulence and dynamic mixing processes. Figure 3 illustrates these features. The horizontal extent of this cross section is 50 nmi. The front is characterized by a high sea surface temperature of 18.6-19.1°C which dips over 10 nmi to a low of 17.8°C at the surface expression of the front and then rises to a lower surface temperature of 18.3-18.4°C. Johannessen et al.¹ suggested that the colder water mass to the east was moving westward underriding the warmer western water. This created a zone of convergence at the front. They suggested that warmer western water was flowing south. It was the strong vertical and horizontal shears predicted by Johannessen's model which gave rise to spikes. The ship's drift indicated that a south current was strongest on the western side of the front at 1.0 to 1.2 knots, whereas on the eastern side flow was at times reversed and had a strength of 0.5 knot. Johannessen et al. identified two water masses: the western side, which had salinity/temperature (S/T) values of 38.08‰/18.96°C, and the eastern side, which had S/T values of 38.30‰/18.25°C.

Levine and White² noted that an oceanic front that has been defined primarily by a thermal profile should more exactly be termed a thermal frontal zone. They define a thermal frontal zone as an area having a horizontal temperature gradient of 1°C/10 km. A thermal front is thus "the sea-surface manifestation of the thermal frontal zone"²; however, a thermal frontal zone does not require a surface manifestation (figure 4). In this case the sea surface temperature did not vary sufficiently to warrant calling it a thermal front. During a cruise of the R/V CHAIN, Levine and White crossed a thermal frontal zone three times in the area of IOMED 71. These crossings were made on 10-11 August 1966. None of these crossings was characterized by a thermal front. In general, they placed the zone lying in an east-west orientation emanating from the Strait of Sicily. Miller³ theorized that this generally east-west character of the zone delineates the approximate boundary between the warm, saline (S/T: 38.83‰/14.5°C) Levantine Intermediate Water in the north moving west along the northern (Malta-Sicily) area of the Sicilian shelf, and the slightly less saline (38.50‰) western Mediterranean water moving east along the south (Africa-Malta) of the Sicilian shelf. Miller describes the region north of the zone as relatively stable, a "plains" region where dynamic mixing is presumably not occurring. The southern region is an area of turbulence and dynamic mixing because water flows from the west and mixes with the Ionian water. He did not note great temperature differences between the two water masses and thus did not expect pronounced seasonal temperature changes.

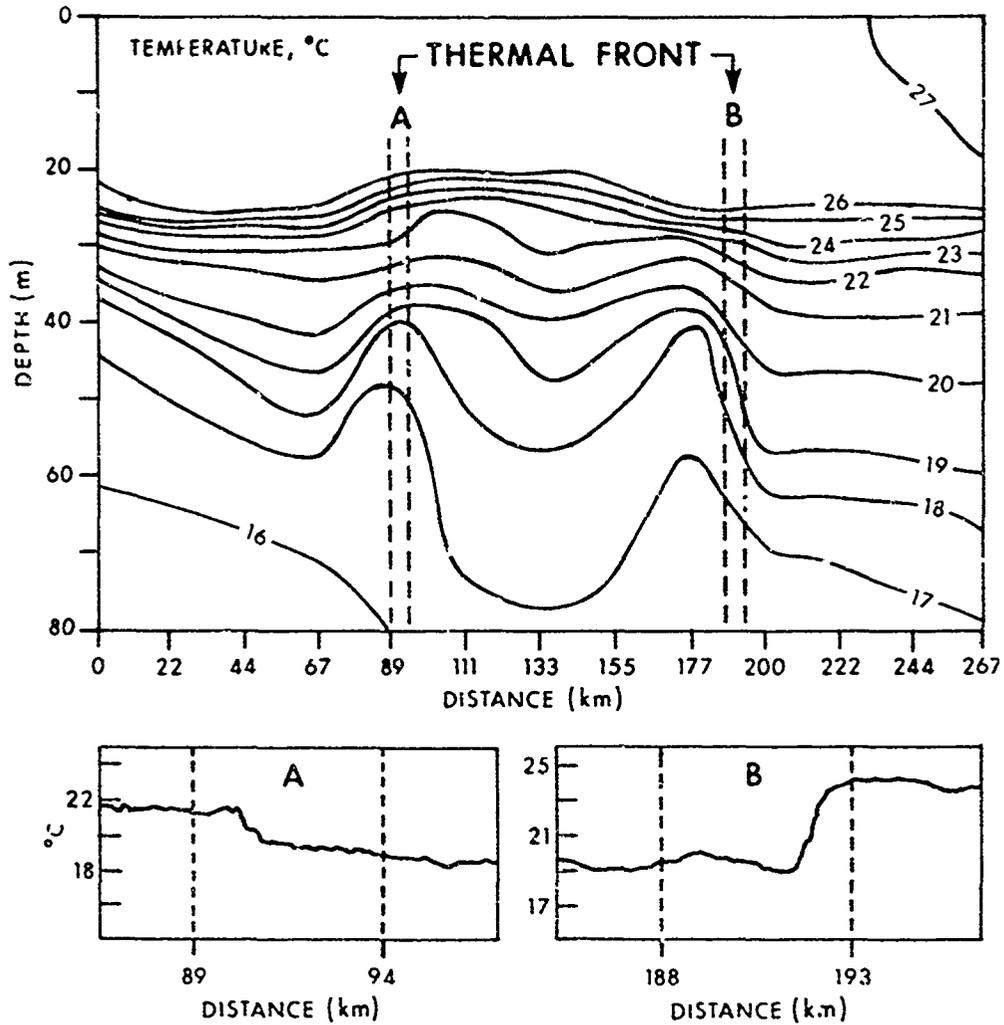


Figure 4. Vertical Temperature Section (above) and Horizontal Temperature Profile at a Constant Depth of 33 m (below) at Thermal Front Zone Crossings. (Reproduced by permission of Levine and White (ref. 2))

METHOD

The primary sources of data were the T7 (750 m) Sippican XBT probes with the MK 3 digitizer/recorder system. The DXBT data were converted to the mks system and printed out (see appendix A). The XBTs were taken at about 50 locations in the IOMED 71 area. Several sound velocity profiler (SVP) casts were taken at four drifting stations. The underway XBT trace locations and the drifting SVP stations are shown in figure 2.

ANALYSIS

The DXBTs were analyzed in several ways. First, a line was drawn between XBT trace 36 (north) and XBT trace 19 to the south. (See figure 2 for location of all sections.) Traces which fell approximately on this leg were included in the cross-sectional profile of temperature versus depth and were analyzed as the north-south (N-S) leg. Two other shorter lines were similarly drawn: one from XBT trace 27 to XBT trace 16 running east-west (E-W leg), and another a south dogleg from XBT trace 25 to XBT trace 27 (south leg). All profiles were drawn as though viewed from the south or east. Profiles were drawn on two scales, 0 to 120 m and 0 to 850 m. For the latter, only those isotherms below the apparent thermocline were included. Normally this was the 16.5°C isotherm. Three horizontal plots of the area were drawn, one showing the intrusion of Western Mediterranean Water above the Ionian thermocline, another indicating the location of LIW, and the last showing the distribution of the depths of maximum temperature on the traces.

The last plot (figure 5) corresponds almost exactly with the axis of the surface sound channel calculated from the DXBT traces. At places where corroborative SVP casts were made, the depth derived from them is entered in parentheses for comparison. It can be seen that the sound channel axis corresponds to the depth of maximum temperature and thus indicates that in this area temperature is the dominant factor defining the sound channel axis. The discrepancy at XBT 36 (station C) occurred because an isothermal layer extended from the surface to 35 m, but the depth of maximum temperature was defined as 0 m.

The N-S leg shallow (0 to 120 m) profile (figure 6) indicated that the thermocline was located at approximately 61 m and was defined by the 16.5°C isotherms. The gradient in the thermocline over most of this leg was measured at the maximum response of the XBT system, which is 95-percent response over

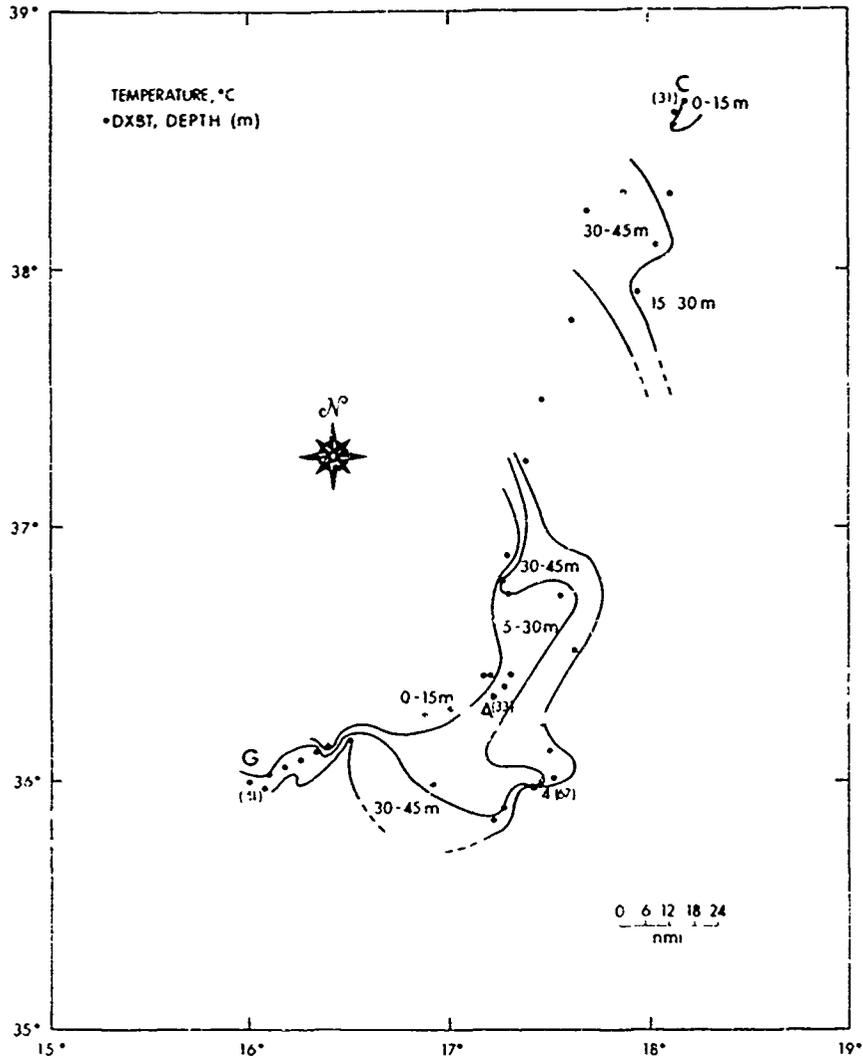


Figure 5. Isobaths of Depth of Maximum Temperature (Numbers in parentheses are the depths of the sound channel axis as determined by SVP.)

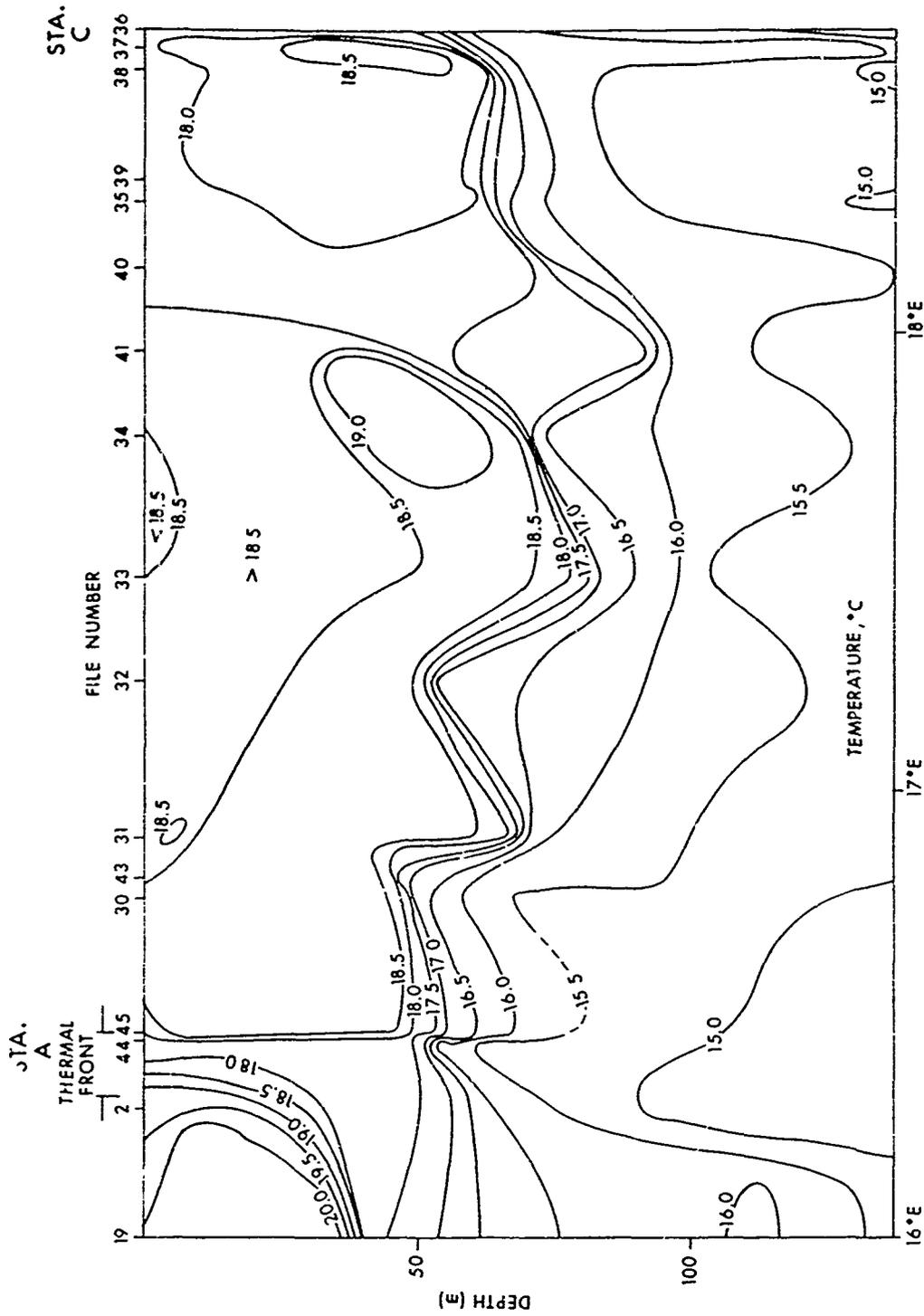


Figure 6. Isotherms Along the N-S Leg (Shallow)

3 m.⁴ It is of course possible that the thermocline's gradient is greater than this, or is even a step or a series of step functions. The thermocline was at 61 m at XBT 19 but was quite broad and diffuse. The intrusive wedge of $\geq 20.0^\circ\text{C}$ water created an apparent thermocline at 38 m. The thermocline dropped as deep as 73 m at XBT 33 and then climbed again to 55 m at the northernmost XBT 36.

Above the thermocline, a more confusing situation was apparent. In the south the intrusive wedge of $\geq 20.0^\circ\text{C}$ water stopped before $36^\circ 18'\text{N}$, and the isotherms were bent sharply to the surface within 15 nmi. Between XBTs 2 and 44 the surface temperature dropped from 19.4°C to 17.9°C , thereby fulfilling the definition of a thermal front as the surface manifestation of a thermal frontal zone. This thermal frontal zone is indicated in figure 6. It represents the probable location of the MALTESE oceanic front as discussed by Johannessen et al.¹ The surface layers became nearly isothermal north of XBT 45 at about 18.5°C with a small wedge of 19.0°C water intrusive at $37^\circ 50'\text{N}$. It is possible that this region, which experienced state 5 seas and 35 knots of wind during SANDS' transit, may have become deeply mixed and may therefore represent the beginnings of the first over-turns of winter. LaFond and LaFond⁵ assumed that observations taken over a 10-day period in the California front were essentially synoptic. In IOMED 71 the same assumption has been made. However, these particular traces (30-36) could be nonsynoptic events.

The MEDOC Group⁶ investigated the formation and descent of Mediterranean bottom water south of France during the winter season. They showed that it is possible for a relatively large area (15×30 nmi) to be acted upon by weather and to maintain a neutrally stable density gradient. They suggested that a large body of water was required before descent would occur, at which time the whole area overturned within a few days. This created large isothermal pools of cool water which plunged straight down displacing warmer water to the sides. The warmer water then found its way up around the periphery of the well-defined cool pool. It is possible that XBT traces 30-36 represent the beginning of such an event. The northern edge of the thermal frontal zone was characteristically marked on all profiles by a dip in the isotherms. This dip may be indicative of turbulence in the more swiftly moving segments of the currents.

The deep profile (figure 7) of the north-south leg indicated a very deep trough of LIW lying astride $37^\circ 00'\text{N}$. According to Miller,³ LIW originates in the Levantine Basin where the surface waters increase in salinity by evaporation and then descend below the surface to seek their own density level. LIW

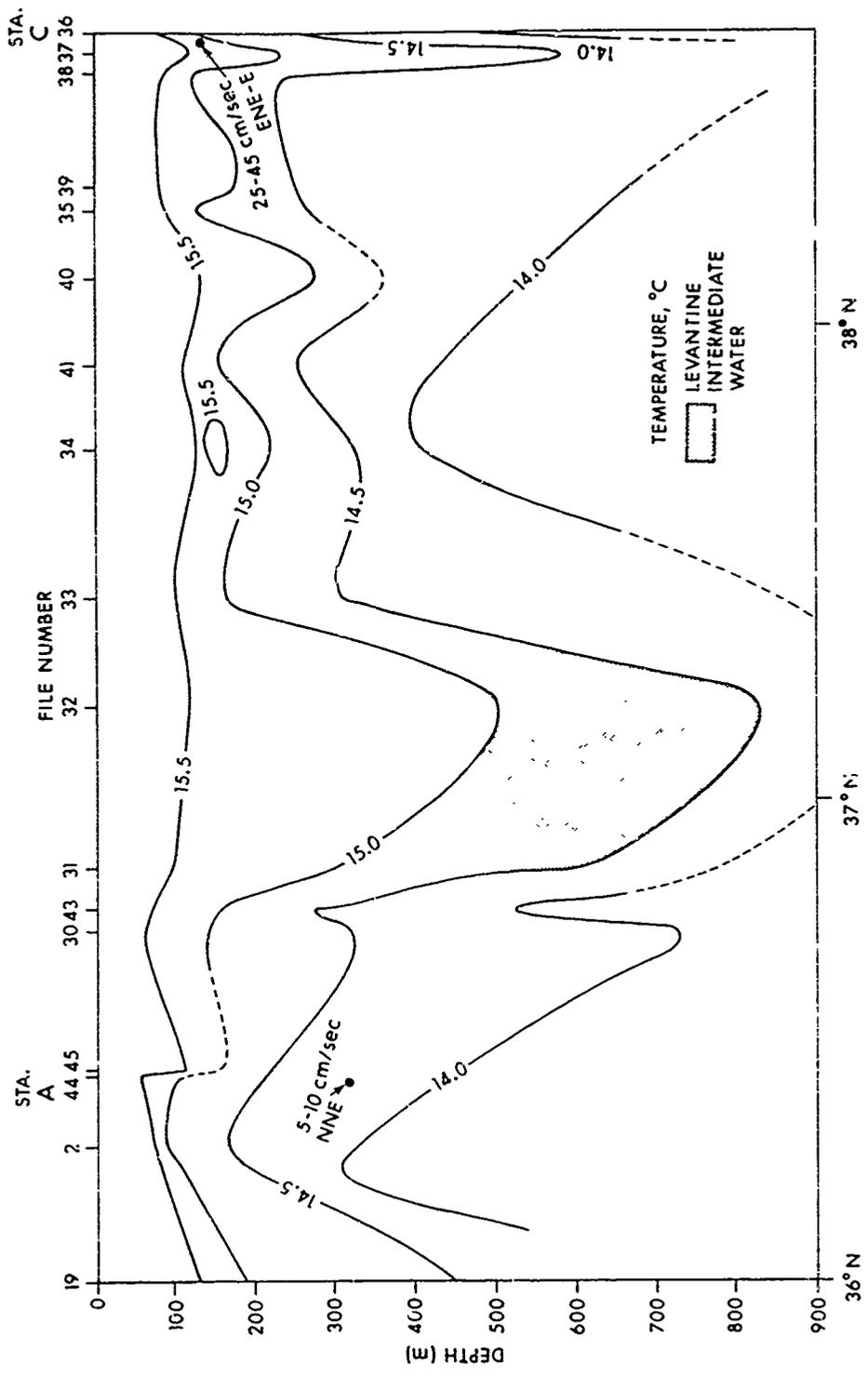


Figure 7. Isotherms Along the N-S Leg (Deep)
(current speed and direction shown from NRL current meters)

has a temperature between 14.5 and 15.5°C and a salinity of 38.8‰. With the evaporative process creating a continual supply of LIW, the only outlet for it is to the west at its own density level. Thus one expects to find LIW in the IOMED 71 area moving west. If the 14.0°C and 15.5°C isotherms are used to define LIW then it lies between 107 m and a depth somewhat greater than 850 m in this north-south leg. Another trough may possibly be present beneath station C. The southern edge of the LIW trough is also characterized by a dip in the isotherms, as is the thermal frontal zone to the south.

Also included on this north-south leg profile are the results of the Naval Research Laboratory (NRL) current meter strings planted in the area as part of IOMED 71. Under the thermal frontal zone at Station A, a 5 to 10 cm/sec current towards the NNE was noted, while beneath station C a 25 to 45 cm/sec current to the ENE or E was recorded. Currents which may have been present or the current strings elsewhere were below the threshold of the Savonius rotors used (5 cm/sec).

The E-W leg shallow profile (figure 8) was characterized by a warm subsurface body of water at $\geq 20.0^\circ\text{C}$. An isotherm of 19.3°C encloses the entire $\geq 20.0^\circ\text{C}$ area of this profile. It surfaces at XBTs 11 and 8 and extends from the westernmost XBT 16 to XBT 2. This warm intrusion of water is considered to be continuous with that which appears under XBT 19 on the north-south leg and therefore represents another look through the MALTESE front. The frontal zone therefore lies in the east under XBT 2, and in the west under XBT 15. Under XBT 16 (station G) there was evidence of further intrusions of $\geq 20.0^\circ\text{C}$ water as the 19.3°C isotherm parted, and numerous temperature inversions were evident. Again the isotherms were bent up sharply to the surface at XBT 44 indicating the thermal front. East of the front the warm wedge was again encountered, and it continued to the easternmost XBT 27. The thermocline, defined by the 16.5 to 17.5°C isotherms, was more varied in depth than it was on the N-S leg. It varied between 43 m and 64 m but centered at about 55 m. Above another trough of LIW, temperature reversals were dominant. XBT trace 13 has been included to illustrate this point (figure 9). It shows the $\geq 20.0^\circ\text{C}$ core, the temperature instabilities beneath it, and the deep trough of LIW below.

In a region as active as this there may be little horizontal spatial coherence between XBTs taken at 5-nmi intervals, as were most of those in IOMED 71. A series of five traces were taken over a 40-min period at 1.3-nmi intervals to see how horizontally coherent the temperature structure was (figure 10). In this case it was relatively stable with a deep pocket of $\geq 19^\circ\text{C}$ water lying above the thermocline. The thermocline undulated slightly between 55 m and

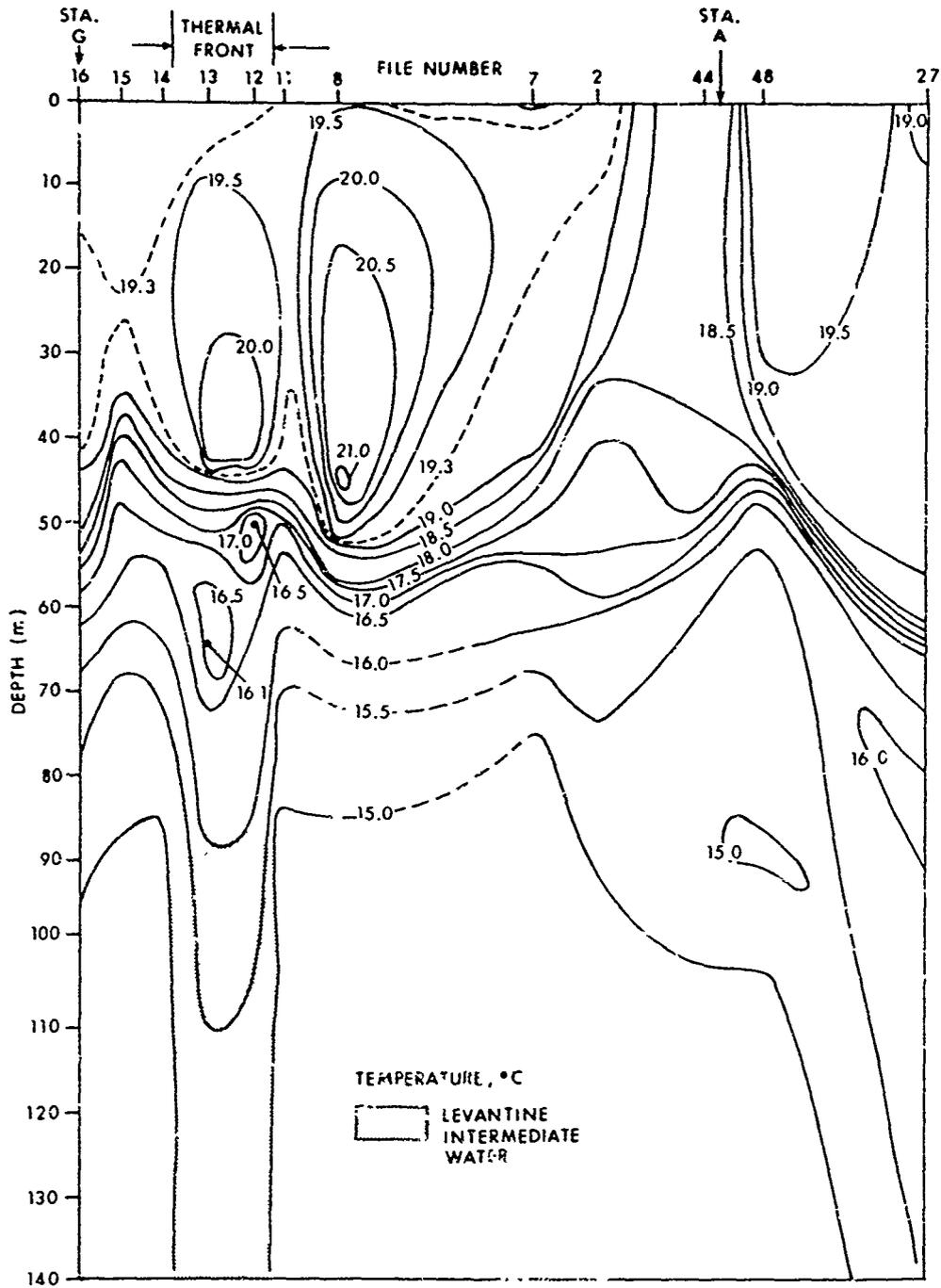


Figure 8. Isotherms Along the E-W Leg (Shallow)

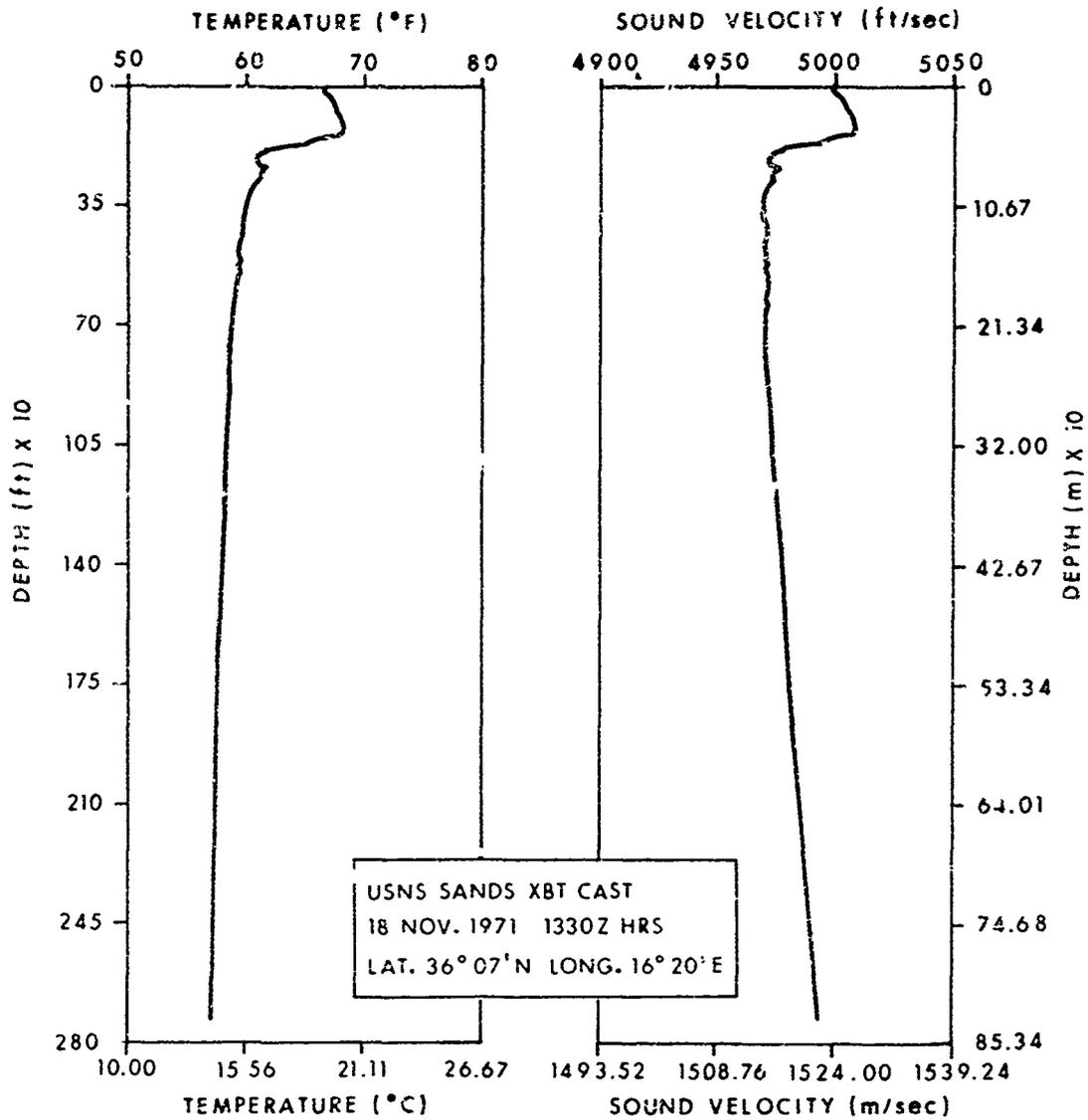


Figure 9. Digitized XBT Profile Showing $\geq 20.0^{\circ}\text{C}$ Water Core

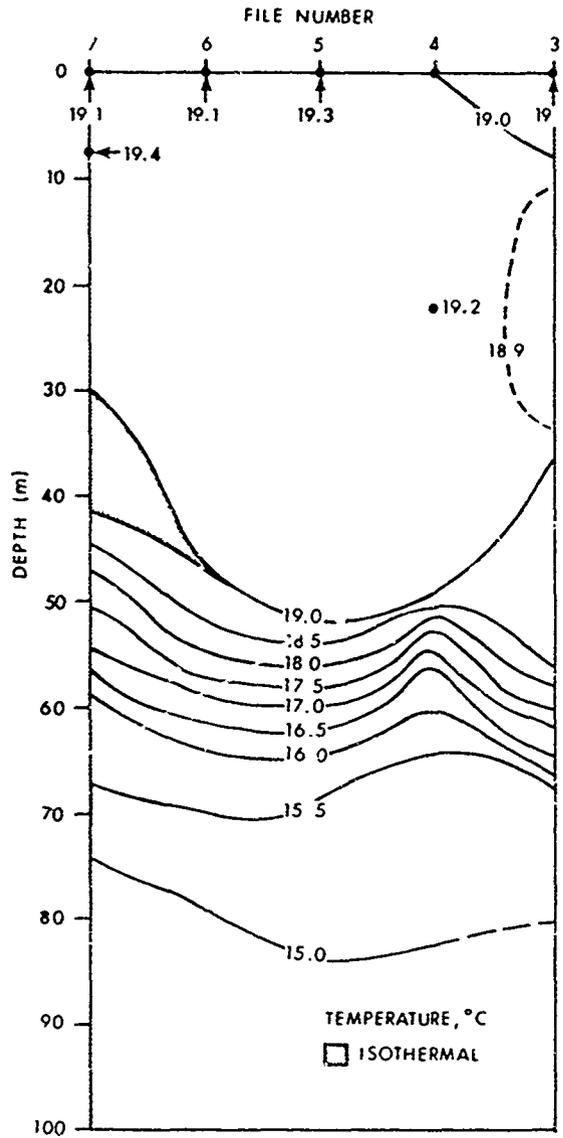


Figure 10. Isotherms Derived from Consecutive DXBTs File Numbers 3-7 (Shallow)

64 m. XBT trace 7 was considered representative, and was used in the overall analysis. However, the contrast between the relatively straightforward XBT trace 7 and XBT trace 13 indicates that XBT trace 13 is a sample of a more confused region. Studies of the structure of turbulence in the California thermal front by LaFond and LaFond⁵ found that isotherms have wavelengths which varied from less than 0.1 nmi to 2.9 nmi, with the median being 0.68 nmi. Even the spacing of XBTs 3 through 7 in the present study was too wide to see wavelengths this small. Nevertheless, wavelengths on the order of 0.5 to 1.0 nmi may be characteristic of turbulence in the thermal frontal zones. Johannessen et al.¹ found (figure 3) that the profile of their thermistor string tow through the MALTESE front showed minor waves whose wavelength approximated that of LaFond and LaFond. Therefore only gross features of turbulence are large enough to be seen by a 5-nmi sensor spacing.

In the deep profile for the E-W leg (figure 11) the LIW showed up as a deep trough centered at 16°15'E and lying from 106 m to 776 m. Again, a sloping down of the isotherms was noted to the west of the LIW. To the east the isotherms again began a sharp decline. This trough corresponded to the location of a similar trough in the 15°C isotherm noted by Miller³ and can be taken as another location of LIW. The waveform in the isotherm located beneath station A appears to have a wavelength of 12 nmi.

The south leg shallow profile (figure 12) was by far the most confused. The majority of the traces were made within a day or two and thus should represent a synoptic condition. The strong wedge of $\geq 20.0^\circ\text{C}$ water was present, centered around station 4. The thermocline sharply descended at this point (beneath XBT 26) with the 17.5°C isotherm being nearly 122 m down and the 15.5°C isotherm at 528 m. This was reflected in the deep profile (figure 13) as well, where two troughs showed up with increased turbulence evident at the southern end. Again a dip in the isotherms was found, this time south of the LIW trough. The dip was observed with several temperature reversals.

On the horizontal isothermal plot (figure 14), the extent of the warm $\geq 20.0^\circ\text{C}$ shallow wedge was apparent. It can be seen to form the basis of a frontal zone stretching roughly west to east along 36°N with a long finger spread northward at 17°30'E. Included also in the plot are suggested streamlines. These suggest that eddies extending horizontally over tens of nautical miles may exist. These eddies would extend down to the thermocline and, as seen under station 4 (XBT traces 23, 20, and 21; figure 15) they may mix with the waters beneath the thermocline destroying its barrier quality.

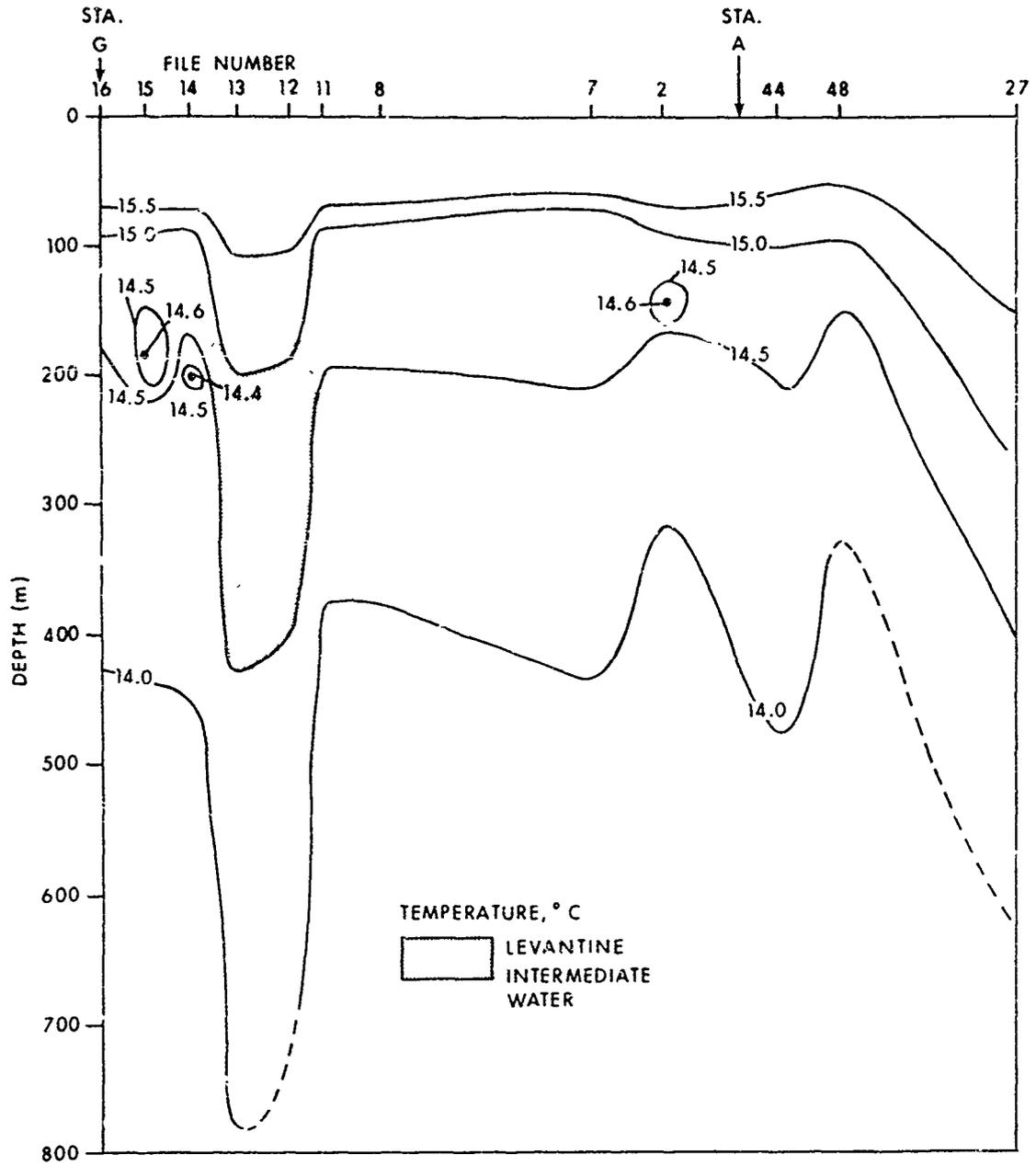


Figure 11. Isotherms Along the E-W Leg (Deep)

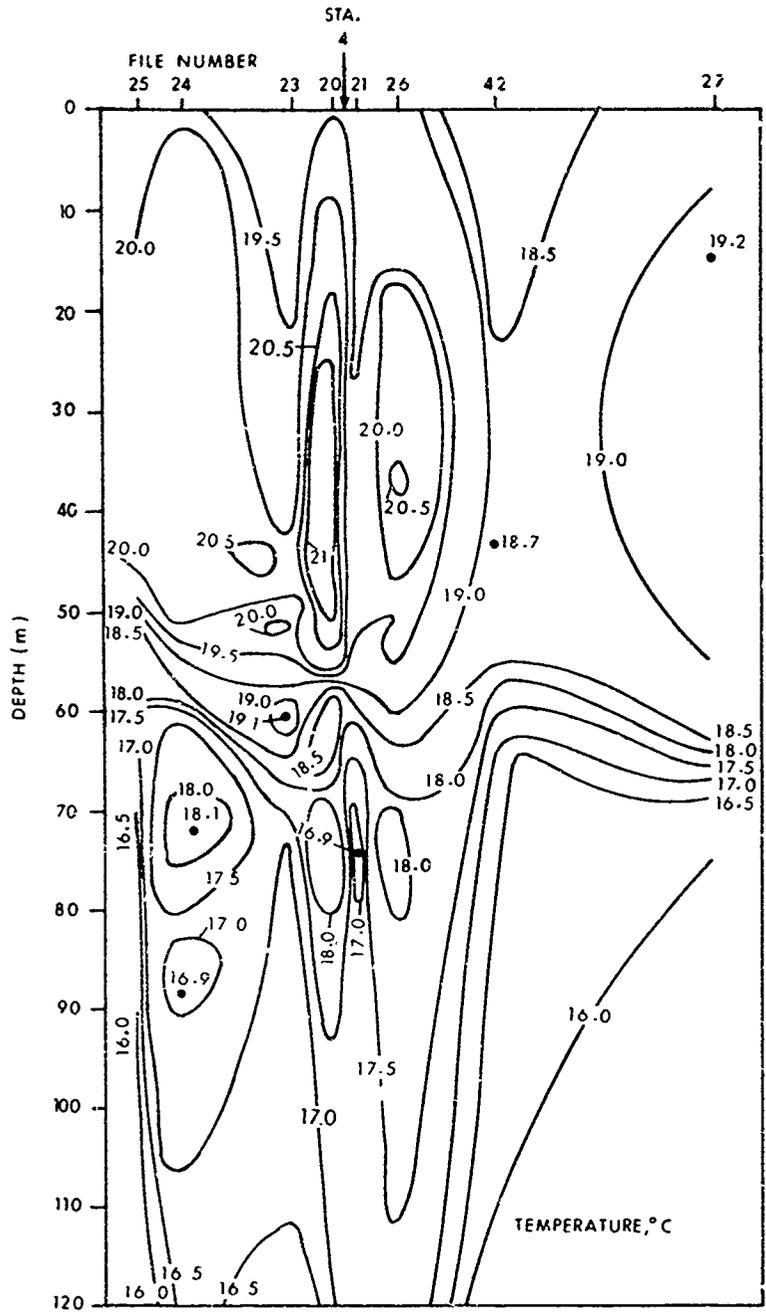


Figure 12. Isotherms Along the South Leg (Shallow)

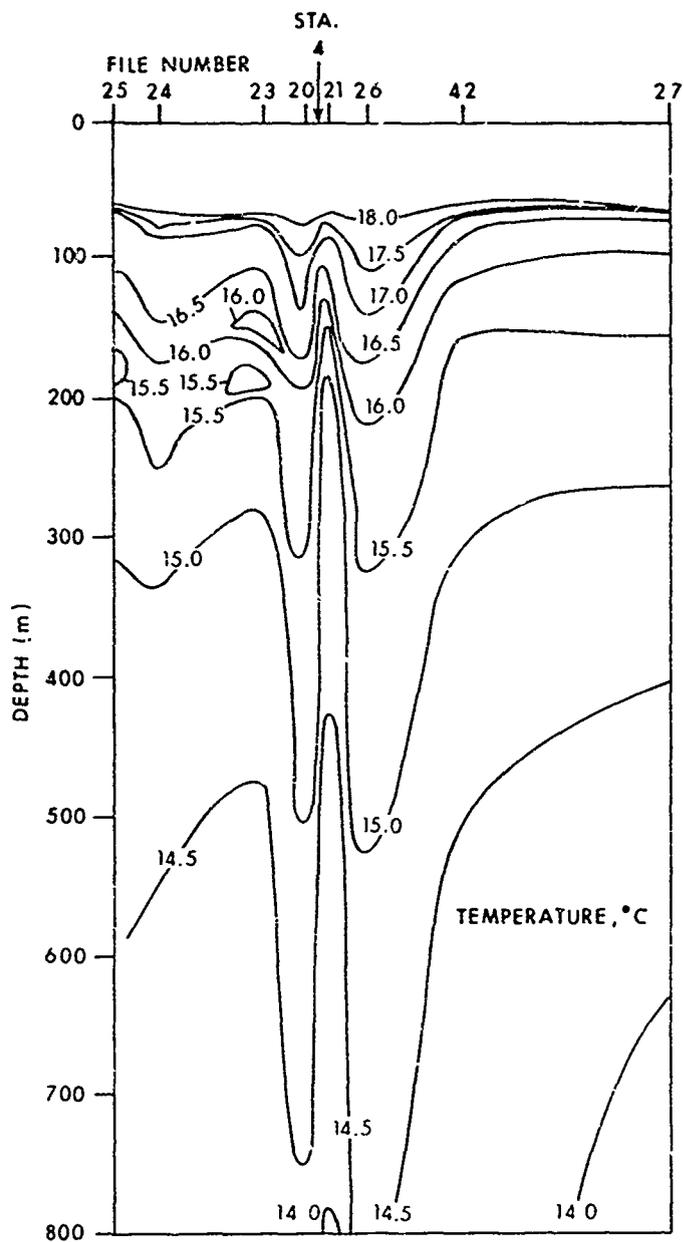


Figure 13. Isotherms Along the South Leg (Deep)

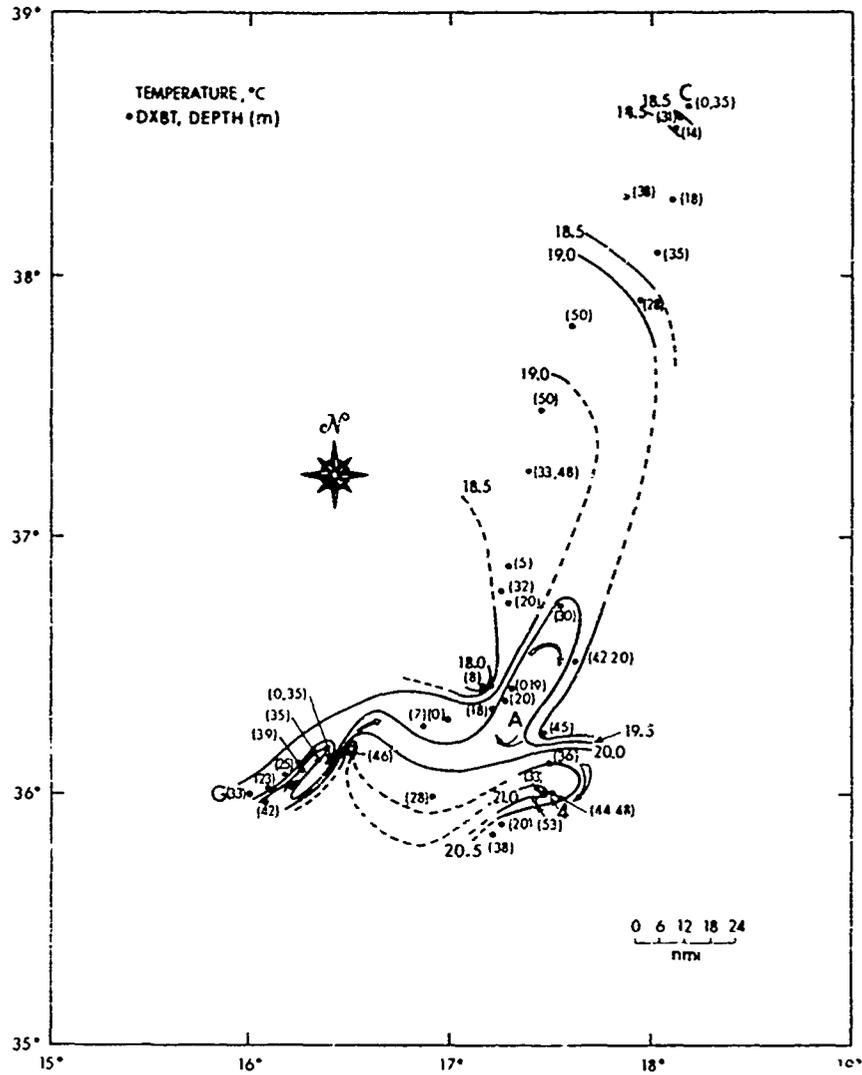


Figure 14. Intrusion of 18.5-21.0°C Western Mediterranean Water Above the Ionian Thermocline and Its Presumed Flow (Numbers in parentheses are depth of maximum temperature (m))

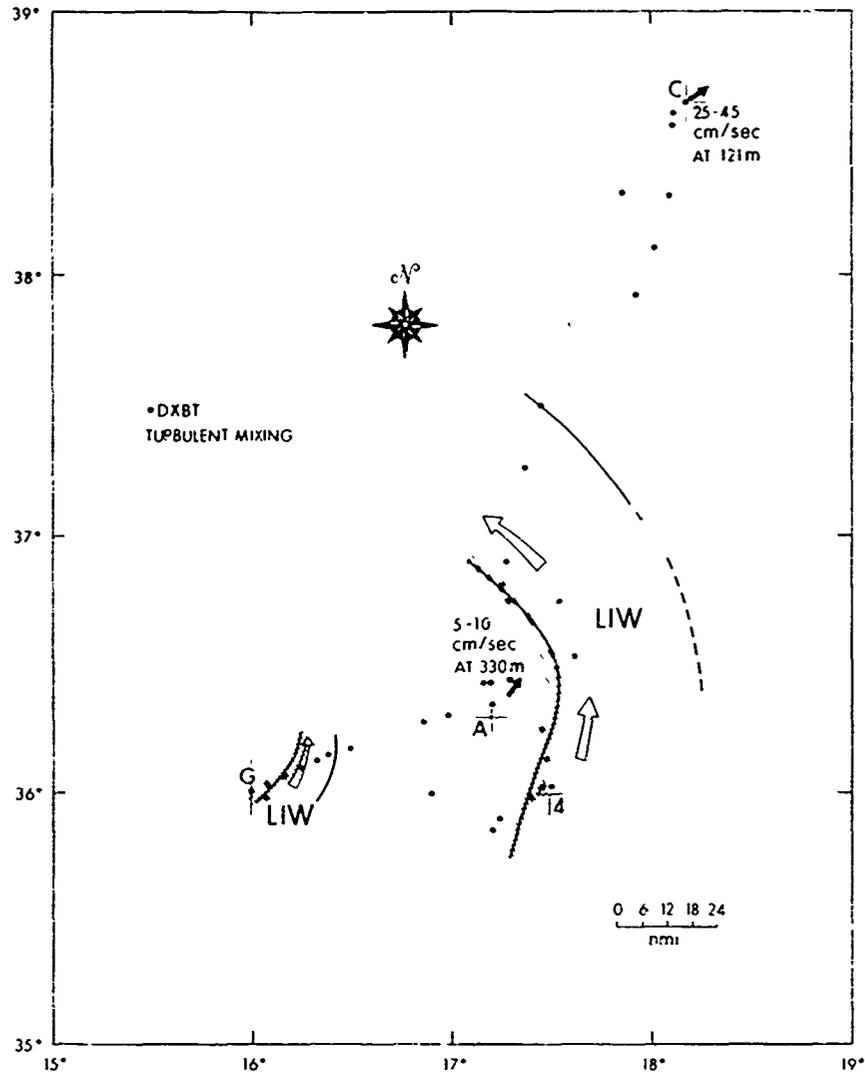


Figure 15. Location of Levantine Intermediate Water and Presumed Flow (Solid arrows indicate measured values; open arrows show presumed flow.)

DISCUSSION

It is misleading to represent this area as having "a front" or "a frontal zone" when it is probable that there are whole areas of fronts or zones in this region which represent the whorls and eddies where two dissimilar water masses mix. A thermal frontal zone is an area where two water masses are meeting. It is not necessary that they be convergent or coincidental or overriding. Each type of current flow will produce its own characteristic pattern. Convergent flows must satisfy mass conservation relationships and so intense mixing at density shears will produce a third water mass which will move to offset the influx of the parent flows. Coincidental flows moving in the opposite or the same directions will create a shear zone of eddies similar to the north wall of the Gulf Stream. Coincidental or parallel flows can be moving at the same or at different relative velocities, and as the velocities differ, so will the degree of vorticity imparted to the eddies created. Overriding water masses probably behave like horizontal examples of coincidental flow. The section of the MALTESE frontal area investigated by Johannessen et al.¹ and this study probably represents this last case. The eastern body of water was underriding or being overridden by the warmer water to the west. Vertical eddies ("spikes") were set up as the vorticity so generated was being bled off. It is possible that some of the wave-like features contoured on the vertical profiles previously mentioned were chance samplings through these vertical eddies. Miller³ divided density shear fronts into two types, those whose temperatures are distinctly different, and those whose temperatures are nearly alike. In the IOMED area, there are both kinds of density shear fronts: one between the $\geq 20.0^\circ\text{C}$ water and the surface Ionian waters which is of high temperature difference; and the other between LIW and Ionian Basin Water of relatively low temperature difference. The magnitude of density and current-velocity differences together contribute to the character of the turbulence in the frontal zones.

In the IOMED area east of Sicily, the more swiftly moving portion of the LIW is indicated by increased complexity of the temperature profiles. Thus a large mass of LIW was moving from the southeast region between 106 m and 850 m from the SE and bending to the NNW. This is indicated by an idealized flow diagram (figure 15) which delineates the suggested flow pattern below the thermocline in this area. The 5 to 10 cm/sec NNE current recorded by the NRL current meter string at XBT 44 suggests a movement of water toward the river of LIW moving to the east. The relative lack of turbulence on the outer edge of this movement then implies more slowly moving water. Further to the north a strong current to the NNE or E is indicated by the NRL current meter string beneath XBT 36. However, insufficient data preclude even speculative remarks.

In the IOMED 71 area two distinct water masses, separated by the thermocline, appear to be intruding in and through the Ionian Sea. Above the thermocline the warm water from the south probably represents eastward-moving water from the Africa-Malta straits. This water generally moves eastward to the Levantine Basin after having been warmed by passage over the shallow strait. After it has been cooled a bit in the east and made more dense by evaporation, it sinks to become LIW, which then moves westerly below the thermocline as it seeks an outlet. This, as Miller³ suggests, appears to be north of 37°N and west over the Malta-Sicily strait. Whereas the presence of LIW has been shown during spring and late fall conditions, it is a permanent feature of the area below the thermocline. The extent of the warm inflow from the south and west will depend on transient conditions which dominate processes above the thermocline.

SUMMARY

It has been shown that surface water moving eastward over the Africa-Malta straits becomes warmed to $\geq 20.0^{\circ}\text{C}$ and forms a distinct water mass found above the thermocline in the IOMED 71 area 36°N, 17°E. This western water admixes with the local Ionian Surface Water forming complex frontal zones which can be detected by a thermal probe. These frontal zones may or may not exhibit a surface manifestation, but are characterized by the termination of the core of $\geq 20.0^{\circ}\text{C}$ water.

The second conclusion to be drawn from this study is that the Levantine Intermediate Water (which is presumed to be the western water discussed above, but slightly cooled and increased in salinity) moves westerly at intermediate depths from the Levantine Basin to the Malta-Sicily straits in large troughs. These troughs are characterized by 14.5°C water which extends from the thermocline to at least as deep as 850 m.

Appendix A

XBT DIGITIZER

INTRODUCTION

The MK 3 bathythermograph probe and recorder/digitizer system was developed to measure water temperatures at all depths without stopping the ship, and to produce two records, one the normal depth versus temperature analog graph, and the other a digitized punched-paper tape teletype output suitable for swift transmission to shore. For the IOMED 71 experiments NUSC (New London) acquired on loan from the Fleet Numerical Weather Central, Monterey, two complete MK 3 systems for in-service testing and use. They consist of the conventional recorder and launcher now in common use as well as a logic unit and a punch assembly.⁴ The dry laboratory space occupied by the system is approximately three times that required for the recorder assembly alone, yet is still acceptably compact.

The punch assembly produces a punched tape in teletype format which contains the ship's international call sign, date, time, latitude and longitude, and coded temperature groups. The unit senses and records the temperature every 8.4 ft for 100 groups (840 ft). After 100 data points, the sampling interval is automatically switched to one data point every 84 ft. (On 6000 ft probes, the sampling rates are slightly different: 8.9/89 ft.)

DATA AND ANALYSIS

The digitized XBT (DXBT) system was used aboard SANDS during the period 18-24 November 1971. During this time 50 usable punched tapes were produced using the type T7 (750 m) probes. Figure 2 shows the ship's track during this period. DXBT traces are listed by an artificial tape sequence file number corresponding to the file number given the tape during computer analysis. Missing file numbers were discarded during hand analysis. All of the retained tapes' outputs were recorded as CalComp plots of temperature and sound velocity versus depth.

Each punch tape was initially put into suitable format for entry into a UNIVAC 1230 computer; then a rough printout was edited to remove apparently

bad traces. The computer program was written to reject traces which jumped incrementally below 840 ft. The remaining 48 tapes were used to compute sound velocity at all digitally sampled depths using Wilson's equation. A historical salinity profile, considered representative of the area, was used for a salinity input. This profile was taken in November 1970.

In order to determine the validity of computed sound velocities, they were compared with SVP casts taken in proximity to the DXBTs. Figure A-1 illustrates how XBT trace 16 compares with the station G down SVP cast. (Refer to figure 2 for station locations.) In the first 50 m the XBT sound velocity ran about 1.6 m/sec higher than that derived from the velocimeter cast. As the XBT probe passed through the thermocline at 60 to 80 m, the computed sound velocities were generally lower than those derived from the SVP by several m/sec. Below 125 m the computed sound velocities were uniformly 0.7 m/sec greater than those derived from the SVP.* It could be argued that the XBT in this case was sampling a water mass significantly warmer than was the SVP; hence the higher sound velocities. This is not the case. If it were a purely random effect, then some XBT sound velocity profiles should be significantly lower than the SVP profiles. However, all of the XBT/SVP comparisons made showed that the XBT sound velocity profiles were higher than the SVP. The assumed salinity profile may be uniformly inaccurate at depth. However, it does agree fairly well with Miller's data,³ which show 38.5 to 38.8‰ as the salinity range for the Ionian Basin. It was also noted that the XBT sound velocities above the thermocline were all higher than the mean. (The mean was calculated disregarding those values in the thermocline.) There is no obvious explanation for this phenomenon. The comparisons between the station 4 SVP cast and the nearby XBT traces 20, 21, 22, and 23 were the worst with a mean of +3.83 m/sec (standard deviation of 0.61). The worst case in point was station 4 downcast versus trace 20. Station 4 and XBT trace 22 agreed the most closely with means of +0.17 and +0.42 m/sec (versus station 4 downcast and upcast, respectively) with XBT trace 21 next closest with +0.97 and +1.26 m/sec. These matches result from the close proximity of station 4 to XBT traces 21 and 22.

In order to determine how internally consistent the SVP casts were, the downcast values were compared with the upcast values. Figure A-2 shows the

*The rated response is one standard deviation within 3 ft (66 percent response) and four standard deviations within 9 ft (95 percent response).⁴

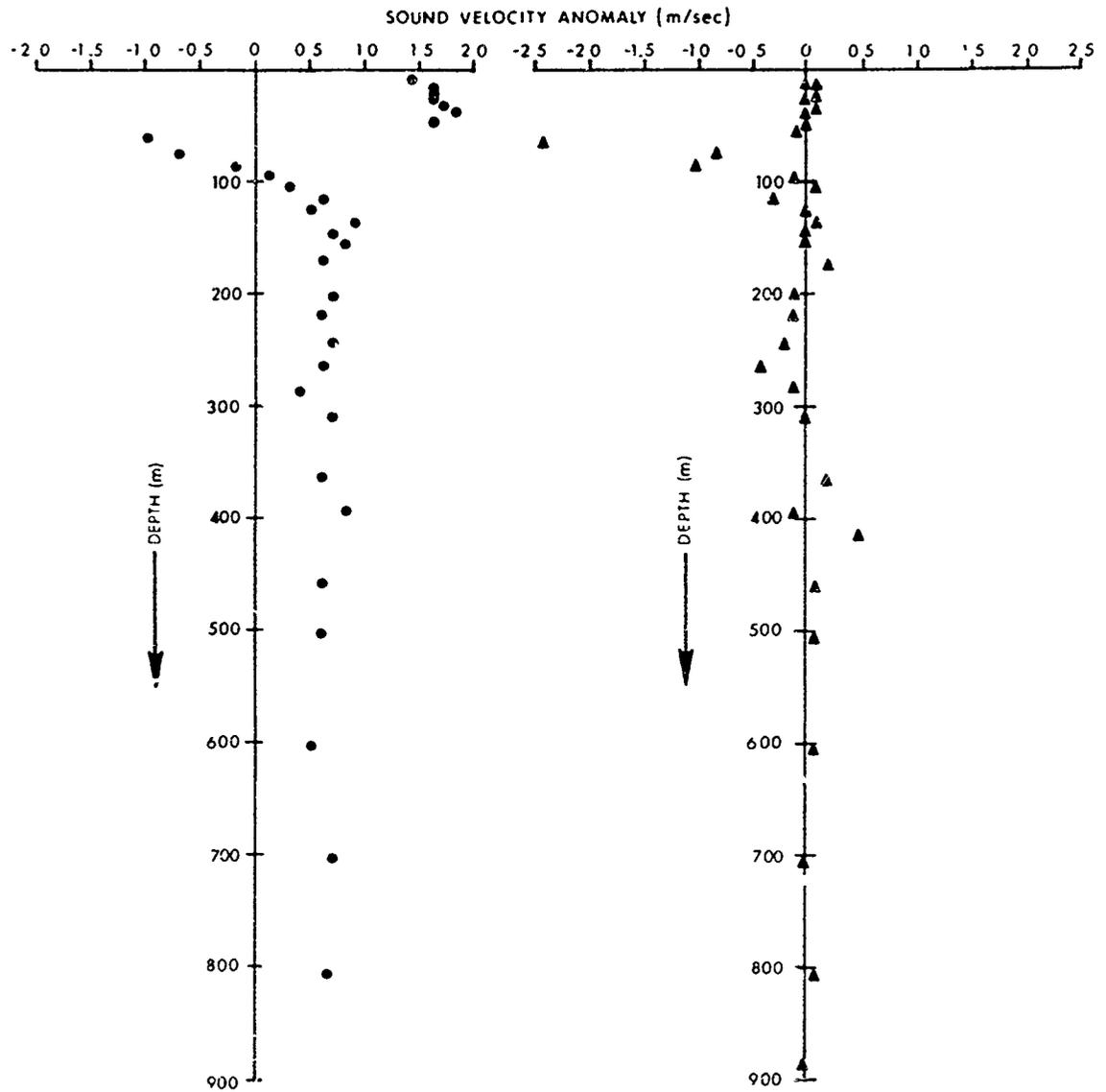


Figure A-1. Sound Velocity Anomaly Between XBT Trace 16 and Station G (Downcast) SVP

Figure A-2. Sound Velocity Anomaly Between Station G Downcast and Upcast

results of this analysis at station G. The downcast values were subtracted from the upcast values. The mean between the two sets of values was 0.0 m/sec with a standard deviation of 0.15 m/sec. However, as with XBT values, in the thermocline there was quite a discrepancy, with the upcast values higher than the downcast values, in this case by as much as 2.4 m/sec. This illustrates that, in the 2.5 to 3.0 hours taken to lower and to raise the SVP, the ship had drifted enough so that the structure of the thermocline sampled was different.

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