THE MALTESE OCEANIC FRONT: A SURFACE DESCRIPTION BY SHIP AND AIRCRAFT

by

M.G. Briscoe†
O.M. Johannessen†
S. Vincenzi*
with
G. Furnes**

ABSTRACT

Simultaneous observations by ship and aircraft of an oceanic frontal zone east of Malta in May 1971 show a predominatly north-south boundary between two water masses evidently formed by surface water from the western Mediterranean and by the Ionian Sea. The front is located along the continental slope east of Malta from the southern tip of Sicily to about 35° 30'N where the influences of changing bottom topography and westward-flowing Levantine water probably combine to break up the continuity of the frontal boundary; from that point the front turns to the east southeast and becomes increasingly more difficult to detect from either its temperature or its salinity properties.

Airborne infrared radiation thermometry (ART, or sometimes IRT) was used to obtain maps of the sea surface temperature; one detailed survey of the northern part of the front showed meanders of some 15 nautical miles wavelength and 8 to 10 nautical miles wave width (peak-to-peak horizontal deviation). Towed surface thermistor measurements from the ship agreed quite well with the ART measurements, at least in the regions where ART measurements are valid, i.e. where there is sufficient surface roughness to eliminate sun-glitter problems. Airborne and shipborne expendable bathythermograph measurements were only in fair agreement.

*Laboratorio per lo Studio della Dinamica delle Grandi Masse, Venice, Italy.
**now at: Geophysical Institute University of Bergen, Bergen, Norway.
† SACLANT ASW Research Centre, La Spezia, Italy.

INTRODUCTION

This report describes the surface properties of the Maltese Front during 10-18 May 1971 and compares some of the combined observations from ship and airplane.

Simultaneous investigations of oceanic fronts by aircraft (using mainly airborne infrared radiation thermometers called ART or IRT) and ship have been made in the Gulf Stream by Stommel [Ref. 1] and Maul and Hansen [Ref. 2] and in the Mediterranean by Woods and Watson [Ref. 3] and by Briscoe and Woods (unpublished manuscript).

The Gulf Stream studies were made on a coarse search grid, the previous Mediterranean studies on a fine grid. The present study of the surface and subsurface of the Maltese Front is a medium grid investigation in which simultaneous measurements were taken by aircraft, using ART and airborne expendable bathyermographs (AXBT's), and by ship, using several sensors for measuring temperature and salinity.

The Maltese frontal system has been investigated previously by Woods and Watson in the summer [Ref. 3], by Johannessen, De Strobel, and Gehin in the spring [Ref. 4] and by Johannessen, Good, and Smallenberger in the winter (unpublished manuscript). Also Levine and White touched on the subject [Ref. 5] and Miller has mentioned it [Ref. 6] but neither was a specific study of the front.

The ART (from Laboratorio per lo Studio della Dinamica della Grandi Masse, Venice) was installed in a U.S. Navy P-3 Orion airplane. The ship was the SACLANTCEN research vessel Maria Paolina G. (henceforth MPG). The overall purpose of MAYFROST (an acronym for May Frontal Study) was to obtain a quasi-synoptic picture of the geographical position of the Maltese Front and to study its short term (several hours to a few days) variability.

Prior to the arrival of the MPG in the operating area (bounded by 33° to 38°N, and by 14° to 19°E), two ART/AXBT flights on 10 and 11 May had determined the front's general location as being quite near to the Malta sill where the bottom depth changes rapidly from some 150 m to more than 3000m. Using the ART surface maps the ship sailed directly into the frontal zone with which contact was made 90 minutes after the search started, this saving several days of ship time.

1 OBSERVATIONS

1.1 Airplane Observations

The ART, model PTR-5, manufactured by Barnes Engineering Co., was slightly modified for range expansion appropriate to Mediterranean temperatures. For a general description of the ART techniques employed see Ref. 7; Appendix A summarizes some of the technical details.

Figures 1 to 4 show the contoured isotherms and the flight track for each of the four main flights. Figure 5 displays a smoothed version of Figure 1 which was obtained by averaging over 15 n.mi. (in the western portion) or 30 n.mi. (east of 16°E) sections of the flight track in order to give some low-pass filtering and approximately a square-gridded result. The smoothed version of the other three surface maps are not shown as they are only slightly different from Figure 5; the smoothed plots eliminate much of the day-to-day variations seen in Figures 1 to 4.

1.2 Ship Observations

The surface properties of the front were surveyed from the MPG with a towed temperature-measuring system consisting of a fast-response thermistor installed in a hole cut in the front of a foam-filled construction worker's plastic protective helmet (hard-hat). Even though temperature is not a conservative property, the hard-hat measurements proved quite successful due to the hydrodynamic qualities of the hard-hat when towed upside down*. The thermistor was about 8cm to 10cm beneath the free surface.

The surface salinity was sampled from a bucket dip at least every 10 minutes (1.25 n.mi. at 7.5 knots); shipborne expendable bathythermographs (SXBT's) and towed subsurface temperature probes (crystals) monitored the internal structure of the frontal zone. Other sensors were used as well, but they will not be discussed here.

Navigation for the MPG was based on a digital LORAN-C system supplemented by satellite navigation.

During the survey phase of MAYFROST the weather was generally calm with strong diurnal heating. Because a section 60 n.mi. long takes some 8 hours to complete (at 7.5 knots), the consequent non-synoptic observation of temperature in the upper few metres of ocean is subject to some bias. Therefore, since during May the surface salinity is a more conservative property than surface temperature, we have chosen to show the large-scale map of the frontal geography (Figure 6) obtained from the bucket samples of surface salinity rather than from the towed temperature measuring systems.

The change in salinity across the front is 0.5‰ to 1.0‰, but the details of the frontal shape are obscured by the time variations that existed during the ten days of observations. Nevertheless, the surface-salinity map (Figure 6) is remarkably similar to the smoothed ART map (Figure 5).

Although when covering a large area the diurnal temperature variation biases parts of the ART-based temperature maps, within a small area the temperature pattern is the most sensitive indicator of the front's location. Typically, changes of 1° to 2°C occurred over a horizontal distance of 2 to 3 n.mi., and in several instances the ART reading showed an almost 1°C jump within a distance of less than 50m.

---

*The design of the hard-hat is due to R. Pesaresi of SACLANTCEN.

A detailed comparison of the surface temperature measurements from ship and aircraft is contained in Appendix B.

2. RESULTS AND DISCUSSION

The geographical location of the front in the northern part of the survey area coincides with the edge of the continental shelf displayed in the bathymetric chart, Figure 7. South of 35°30'N the continental slope is much less steep and the deep-water channel through the Strait of Sicily cuts into the frontal zone.

Except for some confusion in the ART and surface salinity maps (Figs. 1-6) at the point where the deep channel crosses the continental slope, the general trend of the frontal boundary follows the slope until about 34°30'N and 17 to 17°30'E where both the slope and the front are difficult to define.

Levantine water flows westward through the deep channel into the Strait [Ref. 8] and it seems likely that this contributes to the breakup of the front at that point (about 35°30'N, 16°E), perhaps through a mechanism related to a combination of vertical and horizontal shear and the quickly changing bottom topography.

In the northern region the changes across the front are 1°C to 1.5°C and 0.6‰ to 1.0‰ for temperature and salinity respectively; both parameters increase from west to east. The density balance across the front is, in fact, determined by the salinity gradient across it, the eastmost water being heavier. The temperature gradient serves to weaken the density gradient but not to change its sign.

South of 35°30'N the front curves rather sharply towards the east-southeast where there is an influx from the west of cooler and less saline surface water from the western Mediterranean.

The water mass characteristics in the northern zone are clearly western Mediterranean to the west of the front, and eastern Mediterranean to the east, but in the southern region near the breakup at 34°30'N the water mass is either of a third type or is of a modified eastern water type. The temperature/salinity diagnostic diagrams for this area are too scarce for us to distinguish more clearly the water types.

At present we cannot prove whether the breakup of the front allows the western Mediterranean water to flow through the frontal zone, or whether the intrusion of the western water is in fact the cause of the breakup of the front.

We have some strong reservations about "front-hunting" with the AXBT alone; its absolute temperatures seem insufficiently precise and the clues provided by the usual inversions are not easily seen on an AXBT trace. As an adjunct to the ART survey, however, the AXBT serves as an indicator of the subsurface structure, which is sometimes most useful. Typically, a front of slope 1:200 with an inversion-layer thickness of 15m would extend over a band some 3 km wide at the surface, if there were no mixed layer. But if there were, for example, a 50m mixed layer then the smeared inversion-layer would cause the surface band of the front to extend over 10 additional kilometers, thus making the horizontal gradients about one-fourth as strong as when there is no mixed-layer.

From the aircraft a 2°C horizontal temperature gradient across the front, even if spread over 13 km by a mixed layer, would be detectable by ART if the observer knew what to look for; hence the value of the AXBT for sensing the mixed-layer depth and aiding the observer to determine the magnitude of the horizontal gradients to expect.

The strength of the diurnal heating measured from the ship was sometimes 2°C in the immediate surface layer; this complicates greatly the interpretation of SST maps that span about the same range of temperatures. A high-pass filter of some 30 n.mi. cutoff (or, for 200 knot flights, about 10 minutes cutoff) would eliminate the diurnal and other large scale features, but allow the horizontal gradients due to the front itself to come through unmolested. This suggestion is of little value to the surface maps displayed here because the strong horizontal gradients are easily visible during later analysis but for the in situ problem of front-hunting with an aircraft, some analogic processing of the ART signal would be valuable.

The two-dimensional gradient operator suggested by Clarke and Renard [Ref. 9] was not used here because of scarcity of data in the north-south direction. When one has the desired equi-spaced grid in both directions, as in Figure 5, then only a few data points remain.

Although the gross patterns of the several ART maps (Figs. 1 to 4) are similar, the detailed differences are complicated and difficult to describe. One general observation is that the outcrop of the front shows a tendency to meander; the insufficient north-south resolution precludes any chance of ascribing a wavelength or wave-width to the meanders except in the northern region where in the 19 May survey a closely-spaced grid was used.

Figure 8 shows (on the left) an enlargement of the isotherm contours of the northern part of Figure 4 and (on the right), to the same east-west spatial scale, the actual uncorrected ART traces for each rung of the ladder-search pattern. The temperature scale by the ART traces is only approximate. The meanders in the surface outcrop of the front have a wave width (peak-to-peak horizontal deviation) of 8 to 10 n.mi. and a predominant wavelength of some 15 n.mi. The ART traces themselves show that the transition from one water mass to the other is extremely abrupt and occurs at the limit of the response time of the strip chart recorder that was being used i.e. in less than 50m horizontal distance.

Although only conjecture at present, the cold water pools west of the front may be due to upwelling, perhaps accompanied by down-welling to the east of the front. Also, the western Mediterranean surface water entering the frontal zone may be the northern branch of the Atlantic surface water that reportedly [Ref. 10] enters and divides into a northern branch and a southern branch along the coast of Africa.

CONCLUSIONS

The Maltese Oceanic Front as surveyed by ship and aircraft in May 1971 was located along the continental slope east of Malta from the southern tip of Sicily for about 70 n.mi. south to 35°30'N. The structure of the front was evidently disturbed by changing bottom topography and westward-flowing Levantine water entering the deep channel through the Strait of Sicily; surface water from the western Mediterranean was observed to flow through the disturbed portion of the front and on into the Ionian Sea.

The precise east-west position of the front was modulated by short-term meanders of about 15 n.mi. wavelength and a waveheight of 8-10 n.mi. South of 35°30'N the front turned to the east-south-east but stayed mainly along the continental slope.

This location/topography correlation has also been noted by Briscoe and Woods (unpublished manuscript) for July-August observations of the front, but did not exist in a December study by Johannessen, Good, and Smallenberger (unpublished manuscript) when the front was found almost 100 n.mi. to the east.

Horizontal changes across the front in May 1971 reached a maximum gradient in the vicinity of 36° to 36°15'N where increases (east-bound) in temperature and salinity of 1.5°C and 1.0‰, respectively, were observed. In this northern region the temperature and salinity jumps were invariably accompanied by minima in the properties to the west of the jumps.

Although the details of the ART maps of SST varied from day to day, the gross patterns over the 10-day observational period corresponded with each other and with a surface salinity map made by the research ship during the same period.

A comparison of temperature sensors from ship and aircraft showed the best agreement between the ART and a thermistor towed 8 to 10 cm beneath the surface; the agreement worsened west of the front where, on the day of the comparison, the sea was very calm and a combination of sun glitter and diurnal heating apparently contributed to ART errors. Expendable bathythermograph measurements from the ship and the airplane showed only a fair agreement, which was best to the west and east and worse in the frontal zone itself. In summary, when we tried to use all the data obtained from various sensors to give a more detailed description of the frontal zone we had more success from analysing each set of data separately and superimposing the several patterns derived, than we did from indiscriminately combining all the data and then making a single analysis. The point is that we can combine the gross patterns but not the details.

Certain characteristics of the Maltese front are good clues to its presence and help one during a survey: the main features are the correlation with the bottom topography, the salinity and temperature minimum west of the salinity and temperature jump, and the probability of an inversion on a bathythermograph profile.

This study of the medium-scale properties of the Maltese front is complementary to the finer scale studies by Woods and his co-workers [e.g. Ref. 3]; one significant difference in the approaches is that our coarser resolution tends to smooth the irregularities but emphasizes the spatial extent of the frontal zone, whereas Woods' fine-scale studies show the irregularities themselves but tend to lose the geographical significance.

ACKNOWLEDGEMENTS

This study could not have been performed without the full co-operation of the United States Navy; the interest and advice of Squadron VP-10 and the project officer for this survey as well as the help of the individual aircrews are herewith acknowledged.

The ART technicians from the laboratory of S.V. contributed essentially to the overall effort.

We also wish to thank Dr. J.D. Woods, then of the Meterological Office, for first introducing us to fronts in the Mediterranean.

APPENDIX A

ART Techniques

The ART was mounted in the tail of the airplane to look vertically downward. The expected error of the instrument, including the recorder, was ± 0.1°C; two other main sources of error were the atmospheric absorbtion due to the altitude of the flight (300m), and the fact that sea water in the 8 to 14μm interval does not emit as a black body but rather as one that is slightly grey. These errors were allowed for as described by Saunders [Ref. 11] and summarized below.

The partially corrected sea surface temperature (SST) was calculated from Saunders' formula

$$T_o = A(T_h - T_a) + T_h$$

where T_h is the temperature indicated by the direct ART reading at flight level h, T_a is the air temperature at flight level, A is an empirical coefficient describing the absorbtion of infrared in the column of air between the sea surface and the ART, and T_o is the SST corrected for absorbtion.

Saunders [Ref. 11] suggests 0.1 for the coefficient A, which value was confirmed for our conditions by flights at several heights over the same patch of water.

The air temperature T_a (converted from the measured stagnation temperature) was sensed by a thermistor installed in a shaped body placed 10 cm above the fuselage through the flare hole about halfway back from the nose of the plane.

Ideally, compensation for the non-blackness of the sea surface requires another ART* looking upwards to give the sky temperature. Instead a simplified method was used, again based on Saunders' work [Ref. 11], in which the non-blackness correction is assumed to be 0.5°C to 0.7°C for clear skies, and correspondingly less for heavier cloud covers. A 0.6°C correction was obtained for clear skies at the airport in Sicily by dismounting the radiometer and pointing it upwards. When there were clouds the set of corrections suggested by Saunders were used, although most of the flying was under clear skies. The correction was added to T_o since it serves to compensate for T_o being lower (in our case) than the true (black) SST.

The value of SST corrected for non-blackness and air absorbtion has an accuracy, including instrument error, of ± 0.2°C [Ref. 11].

In addition to the continuous analogue records of T_h and T_a, visual observations of the overhead sky conditions were recorded on the strip chart. Navigation was performed by the aircrew's navigator using various radar and radio systems aboard the P-3 aircraft. The absolute position accuracy was generally less than 3 n.mi. and the relative accuracy for SST gradient estimation was quite good (better than 5%).

*The standard PTR-5 ART does not have a sufficiently low scale to reead the sky temperature. Our ART had been specially modified (by S. Vincenzi) to have the required range.

For analysis, the strip chart record of T_h and T_a was digitized at least once per minute (3.3 n.mi. at 200 knots), the corrections applied, and the resulting SST value placed on a large-scale map of the area to permit hand-contouring of the data.

APPENDIX B

Comparison of Ship and Aircraft Measurements

Figure B-1 shows the tracks of the ship and the airplane during part of 14 May; the caption gives the details of times and symbols. Table B-1 gives the time for each SXBT and AXBT profile.

Figure B-2a contains the temperature profiles from the two BT systems. A problem with the AXBT calibration was resolved by shifting the temperature scale until the deepest temperatures coincided with those of the nearest SXBT; this shift was from 0.8°C to 2.0°C, averaging 1.5°C.

The spatial separation of the SXBT/AXBT pairs varied from zero to 2 n.mi, averaging about 1.4 n.mi. The SXBT/AXBT pairs compare reasonably well except in the vicinity of 15°15'E where the large discrepancies are probably due to the presence of the front; two BT's only a few hundred meters apart may be quite different if near a front.

The internal evidence of a front is the pattern of the isotherms, especially where temperature inversions exist (e.g., AXBT's no. 2 and 3 in Fig. B-2a), but at the surface one must rely on horizontal temperature gradients. Figure B-2b shows the "surface" temperature measured by several techniques at the same "points" as the SXBT/AXBT pairs. In fact, the locations and times for the comparison measurements are not coincident, nor are all the measurements from the same depth. We estimate the ART measurement depth as being within the top millimetre of water, the hard-hat measurement depth within the top 10 cm, the bucket depth within the top 30 cm, the AXBT depth within the top metre, and

SXBT No.	TIME (GMT) 14 May	AXBT No.	TIME (GMT) 14 May
54	0755	1	1207
55	0825	2	1211
57 } 58 }	0910 } 0920 }	3	1217
61	0950	4	1225
63	1030	5	1232
68	1246	6	1250

Table B-1

Times for SXBT and AXBT comparison profiles

the SXBT as being about 2.5 m. During times of strong diurnal heating and low winds one expects these various measurements to compare imperfectly at one point, however in seeking frontal locations it is horizontal gradients that are important.

Figure B-2b indicates that except for the last (eastern-most) comparison, the SXBT "surface" temperature is consistently low, as expected. The AXBT reading of "surface" temperature shows the greatest variability of all the sensors, and would have been even worse if it had not been for the scale shift mentioned earlier. We prefer the hard-hat measurement as the standard for SST because it gives a continuous output, it is accurate to 0.03°C, and it is free of operator bias (unlike bucket temperatures).

Relative to the hard-hat temperature, then, the ART surface temperature is seen to be (in the mean) better than the expected ± 0.2°C, except for the two west-most SXBT/AXBT pairs, i.e. 1/54 and 2/55. Those positions, on the west side of the front, were in a region where the sea surface was insufficiently rough to give non-specular reflection of the solar disk.

From Saunders' [Ref. 12] estimates of the effect on the ART of specular reflection of the sun from a nearly calm surface, we calculate for the area west of the front that an anomalous temperature increase of at least 1°C was expected. The sun was near zenith (76°) and the sea nearly dead calm at the time of measurement. The sea was not so calm east of the front, where visual observation indicated that wind and/or current shear perhaps existed along the frontal boundary.

Also, the diurnal heating of the top few centimetres of water was typically 1°C to 2°C, at least as seen by the hard-hat on other days when the surface water was better mixed.

The 14 May anomalous behaviour west of the front is illustrated again in Figure B-3a: the actual traces of the ART (uncorrected) and the hard-hat (marked "SHIP") are shown on the same temperature and distance scales; the actual times for each sensor are included as well. Note from Figure B-1 that the airplane was westbound and the ship was eastbound, both along 35° 59'N ± 1 n.mi. The front jumped the ship's measurement up by 0.7°C in 7 n.mi., but the ART reading changed in the opposite sense by almost 2° due to the combined influence of specular reflection of the sun's disk and diurnal heating of the upper millimeters of water.

Except for the single instance described above, the ART measurements showed cold water to the west of the front. Figure B3b shows typical traces across the front from the ship's hard-hat and from the ART; the traces were along 36°12'N on 13-14 May and along 36°N on 10 May, respectively. In both cases the front was crossed at about 15°15'E. Note particularly the temperature decrease (eastbound) before the main increase, and the double jump consisting of two plateaus.

Figure B3b indicates that certain features of the horizontal temperature gradient across the front were consistent between both the ship and the aircraft measurements, and that some time stability existed.

REFERENCES

1. H. Stommel, "The Gulf Stream", 2nd Ed., Univ. of California Press, 1965.

2. G.A. Maul, and D.V. Hansen, "A Similtaneous Observation of the Gulf Stream Surface Front Structure by Ship, Aircraft, and Satellite", Transactions of the American Geophysical Union, (1971), 52, 4, 254.

3. J.D. Woods, and N.R. Watson, "Measurement of Thermocline Fronts from the Air", Underwater Science and Technology Journal, (1970), 2, 6, 90-99.

4. O.M. Johannessen, F. de Strobel, and C. Gehin, "Observations of an Oceanic Frontal System East of Malta in May 1971 (MAY FROST)", SACLANTCEN Technical Memorandum No. 169, 15 August 1971, NATO UNCLASSIFIED.

5. E.R. Levine, and W.B. White, "Thermal Frontal Zones in the Eastern Mediterranean Sea", Journal of Geophysical Research (1972), 77, 4, 1081-86.

6. A.R. Miller, "The distributions of Temperature, Salinity, and Sound Velocity in the Western Ionian Sea during Spring, 1968", Woods Hole Oceanographic Institution, Ref. 72-5,1972.

7. P.M. Saunders, "Aerial Measurement of Sea Surface Temperature in the Infrared", J. Geophysical Res., (1967), 72, 16, 4109-4117.

8. G. Wüst, "On the Vertical Circulation of the Mediterranean Sea", J. Geophys. Res., (1961), 66, 10, 3261-3271.

9. L.D. Clarke, and R.J. Renard, "The U.S. Navy Numerical Frontal Analysis Scheme: Further Development and a Limited Evaluation", Journal of Applied Meteorology, (1966), 5, 6, 764-777.

10. A. Morel, "Caractères hydrolugiques des eaux échangées entre la bassin oriental et la bassin occidental de la Méditerranée", Cahiers Oceanographique, (1971), 23, 4, 329-342.

11. P.M. Saunders, "Corrections for Airborne Radiation Thermometry", J. Geophysical Res., (1970), 75, 36, 7596-7601.

12. P.M. Saunders, "Radiance of Sea and Sky in the Infrared Window 800-1200 cm^{-1}", J. Optical Soc. Amer., (1968), 58, 645-652.

CAPTIONS FOR FIGURES

1. Corrected sea-surface isotherms for the ART measurements on 10 May 1972.

2. Corrected sea-surface isotherms for the ART measurements on 11 May 1972.

3. Corrected sea-surface isotherms for the ART measurements on 18 May 1972.

4. Corrected sea-surface isotherms for the ART measurements on 19 May 1972.

5. Corrected sea-surface isotherms for ART measurements on 10 May 1972 (see Fig. 1) after smoothing by averaging the east-west measurements over 10 n.mi. to 30 n.mi. intervals to give a square-gridded result.

6. Sea-surface isohalines drawn from samples made at 10 minute intervals during the period 13-20 May 1971.

7. Bathymetry of the survey area, based on a combination of U.S. Naval charts H.O. 3920, 0.0.3921, and H.O. 3926.

8. Details of the ART measurements on 19 May 1971. (a) isotherms (b) the flight track with the northern legs numbered, (c) the raw ART trace for each of those numbered legs.

B-1 Tracks of the ship and the airplane during the sensor comparison study on 14 May 1971. The black circles are positions of AXBT profiles, numbered with the bold-face figures. The open circles are SXBT profiles, numbered with the two-digit light-face figures. The times for each of the profiles are given in Table B-1; the portion shown of the ship's track occurred between 0500 GMT and 2030 GMT on 14 May 1971. The portion shown of the airplane's track occurred between 1145 GMT and 1305 GMT, also on 14 May 1971.

B-2 (a) Comparison of SXBT and AXBT at nearby points given in Fig. B-1 and Table B-1. Due to calibration problems, the AXBT traces were shifted to force their deep temperatures to coincide with the nearby SXBT deep temperatures.

(b) Comparison of the surface temperatures at six positions shown in (a). At each position there were measurements by SXBT, AXBT, hard-hat, ART, and bucket (except at the position of SXBT 68).

B-3 (a) Comparison of ship's towed thermistor (hard-hat) and ART measurements for the coincident ship-airplane track along 36°N, as shown in Fig. B-1.

(b) Comparison of ship's and airplane's sea surface temperature tracks for two different days but the same location. The two traces are to the same vertical and horizontal scale but have different vertical baselines.

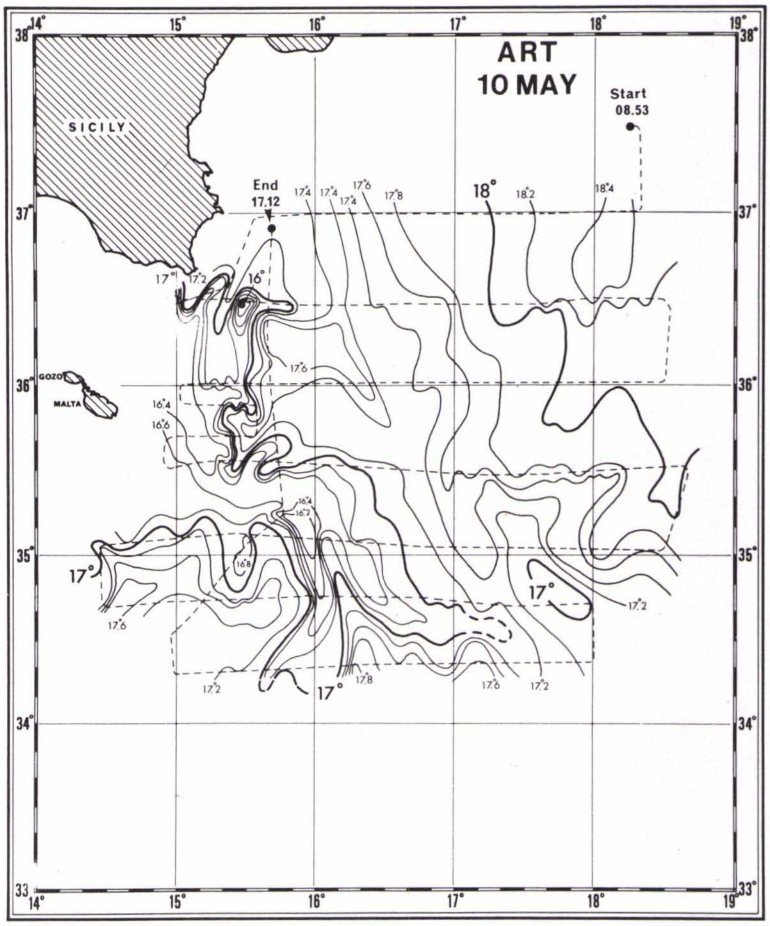

ART
10 MAY
Start
08.53
End
17.12
SICILY
GOZO
MALTA

FIG. 1

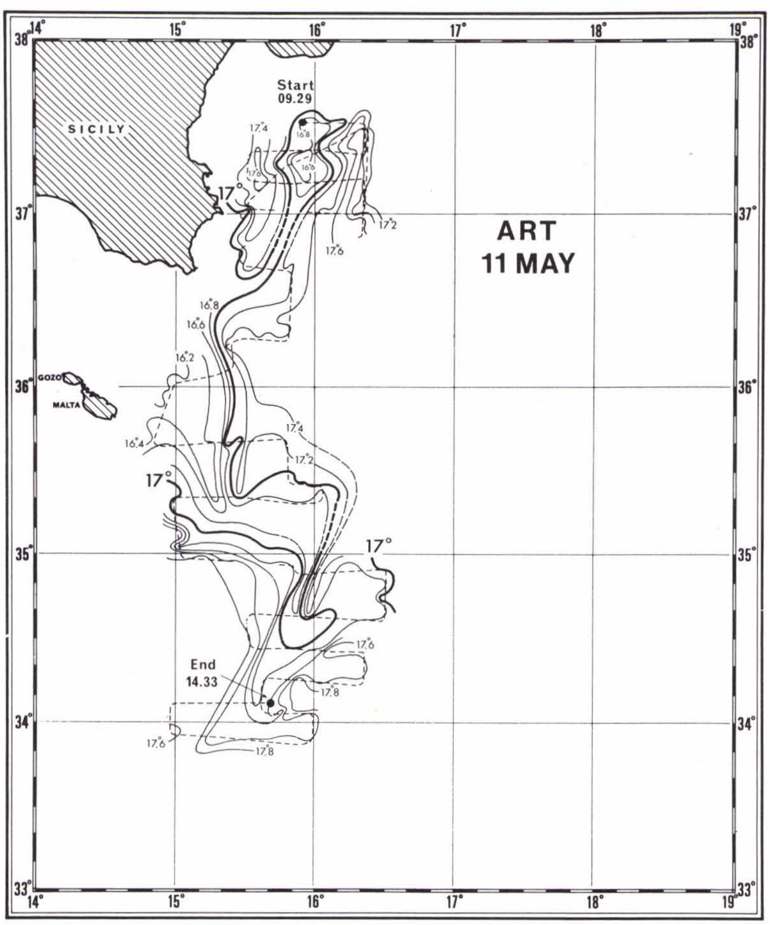

ART
11 MAY
Start
09.29
End
14.33
SICILY
GOZO
MALTA

FIG. 2

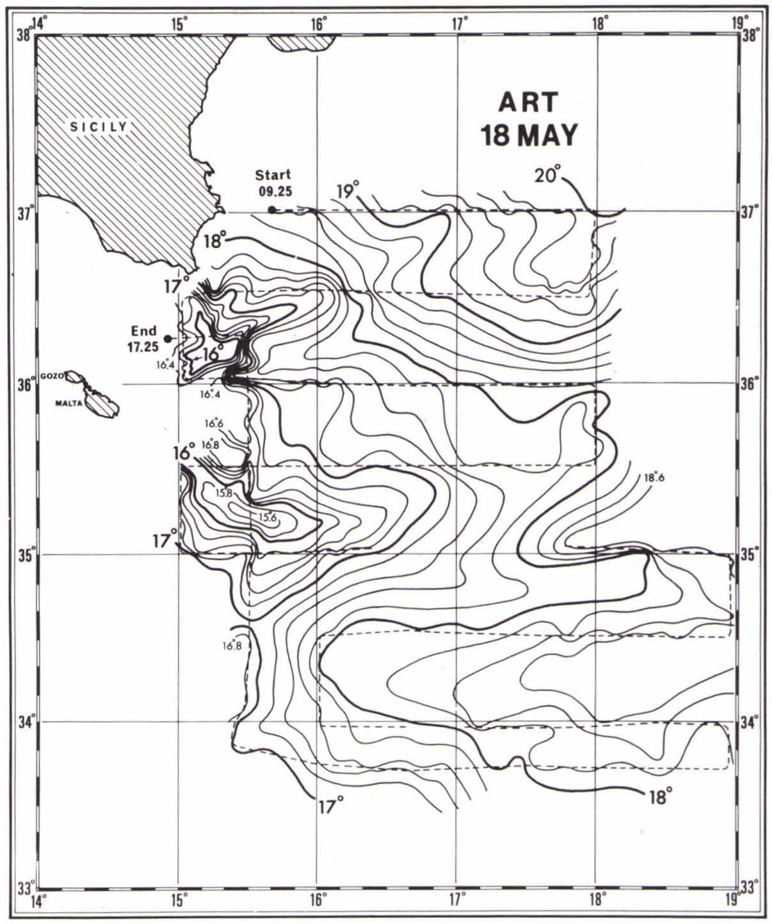

ART
18 MAY
SICILY
Start
09.25
End
17.25
GOZO
MALTA
19°
20°
18°
17°
16°
16.4
16.6
16.8
15.8
15.6
18.6
17°
18°

FIG. 3

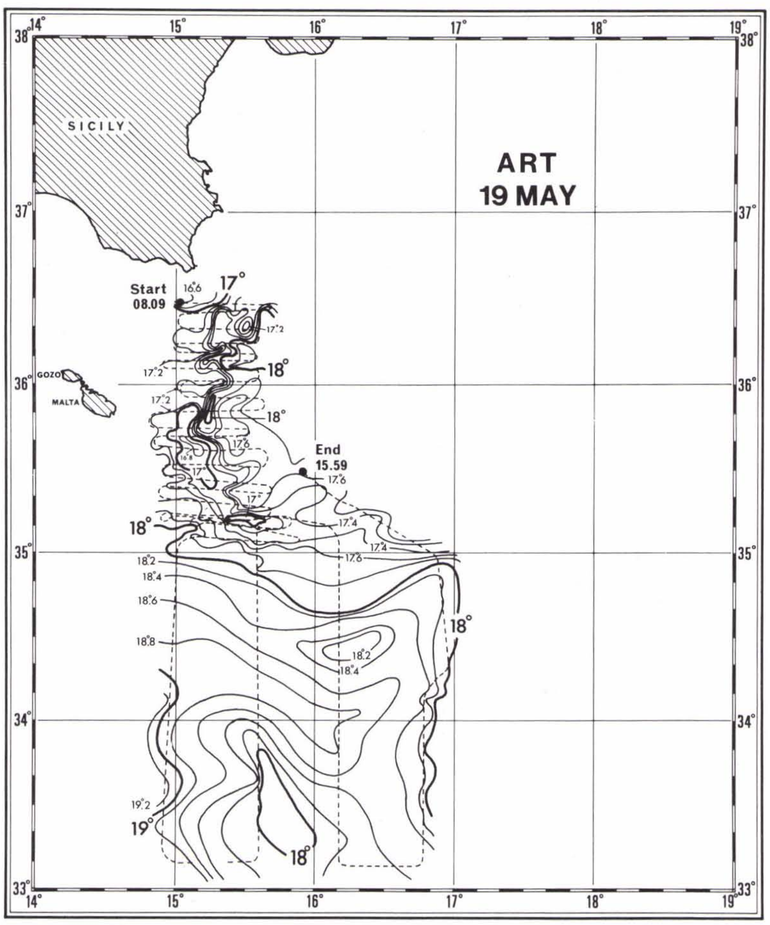

ART
19 MAY
SICILY
Start
08.09
End
15.59
GOZO
MALTA
17°
18°
19°
17.2
18.2
18.4
18.6
18.8
19.2

FIG. 4

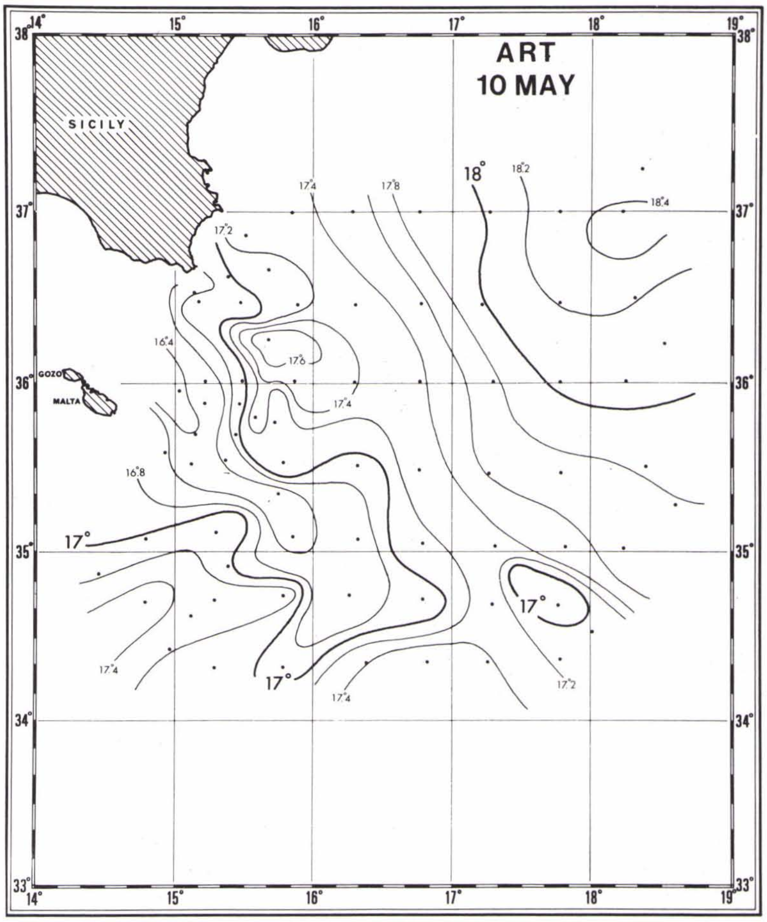

ART
10 MAY
SICILY
GOZO
MALTA
18°
18.2
18.4
17.4
17.8
17.2
16.4
17.6
16.8
17°
17°
17°
17.2
17.4
17.4

FIG. 5

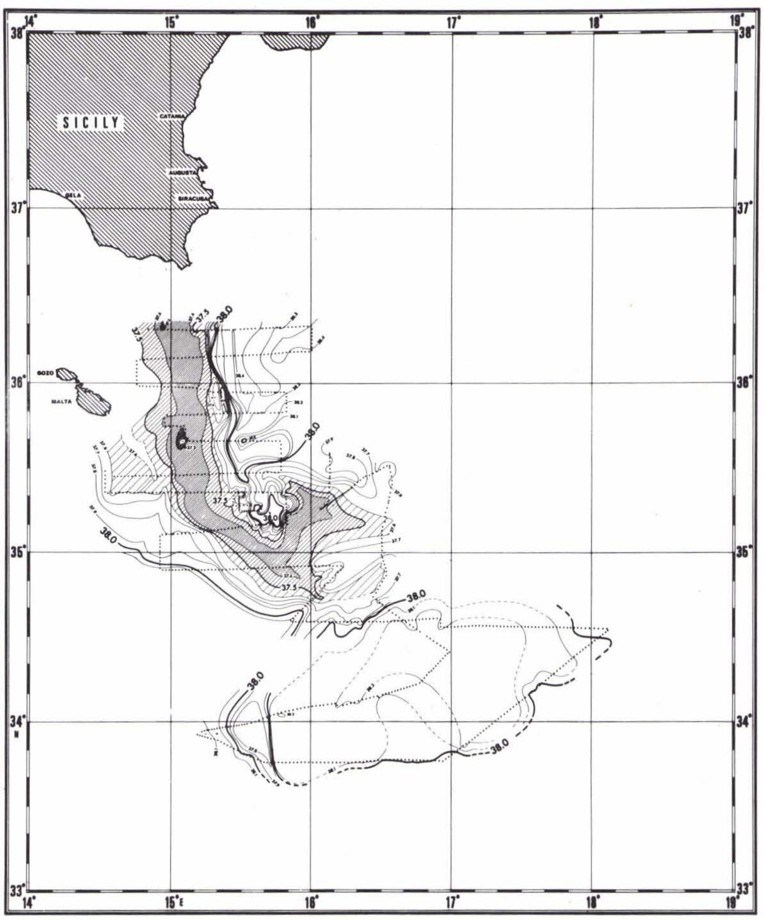
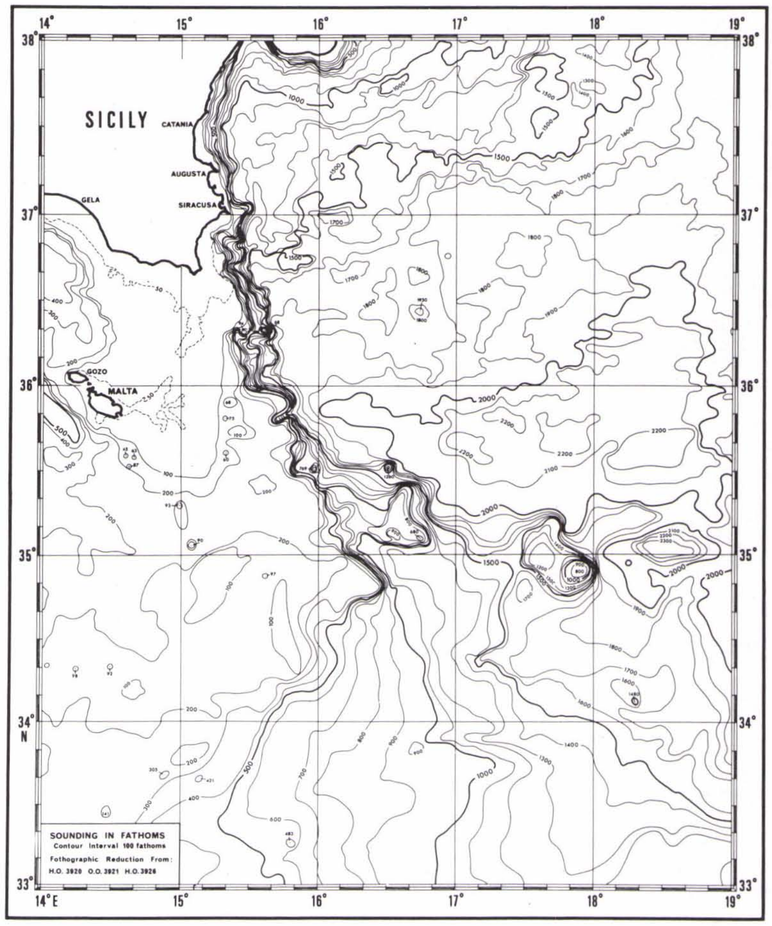
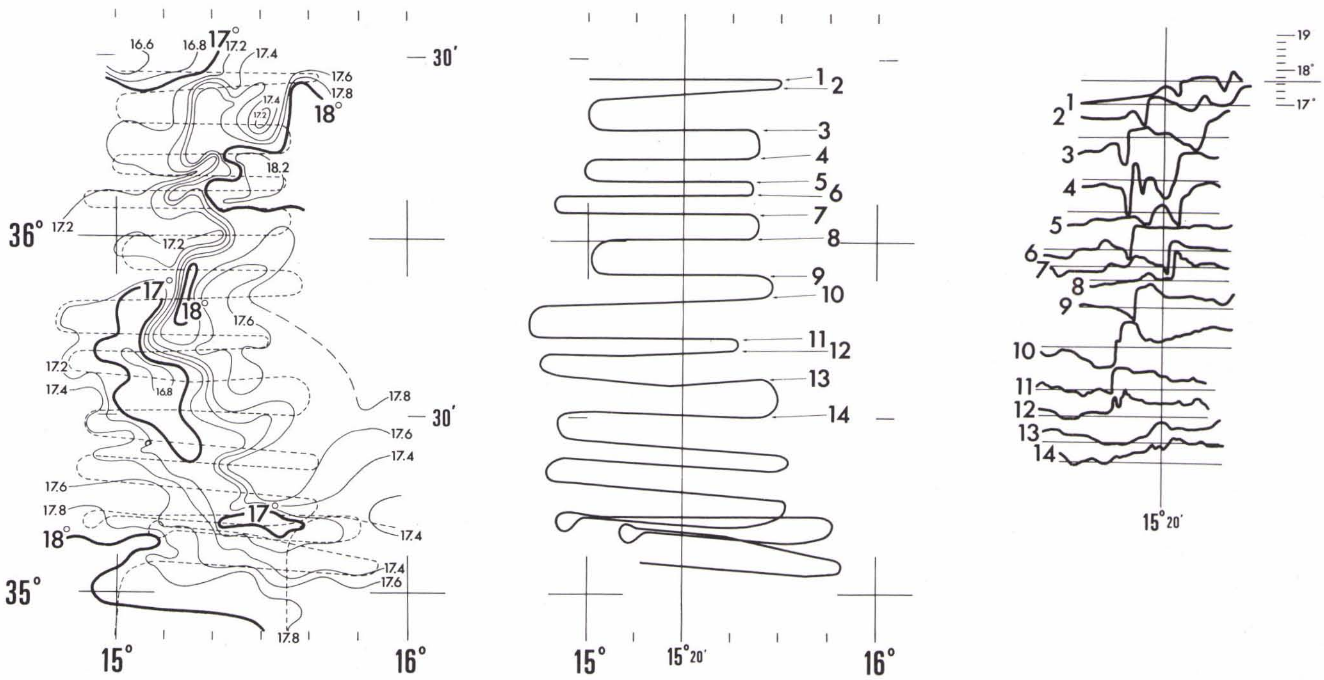

SICILY
CATANIA
AUGUSTA
SIRACUSA
GELA
GOZO
MALTA
38.0
37.5
38.0

FIG. 6



SICILY
CATANIA
AUGUSTA
SIRACUSA
GELA
GOZO
MALTA
SOUNDING IN FATHOMS
Contour Interval 100 fathoms
Fotographic Reduction From:
H.O. 3920 O.O. 3921 H.O. 3926
14°E
15°
16°
17°
18°
19°
38°
37°
36°
35°
34°
N
33°

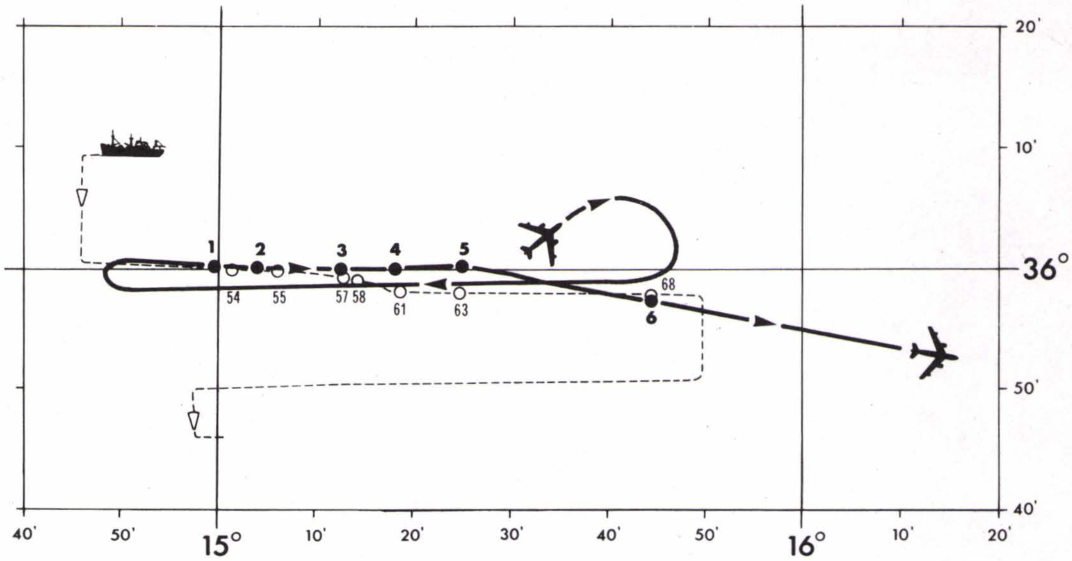
FIG. 7



16.6
16.8
17°
17.2
17.4
17.6
17.8
18°
18.2
30'
36°
35°
15°
16°
15°20'
1
2
3
4
5
6
7
8
9
10
11
12
13
14
19
18°
17°

FIG. 8

FIG. B.1



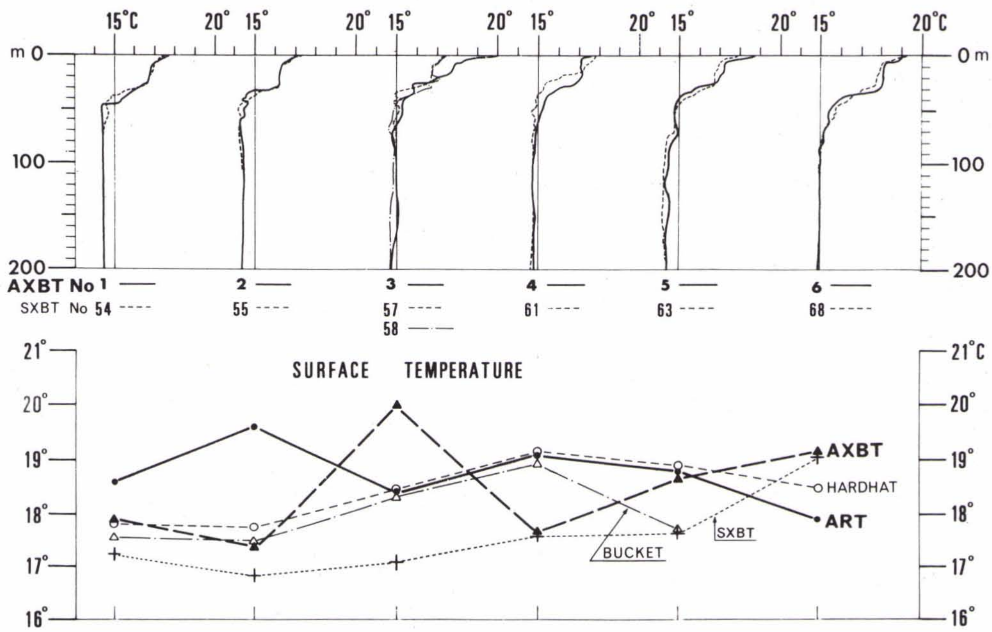


FIG. B.2

FIG. B.3