LEVANTINE INTERMEDIATE WATER

AND

ITS CONDITION WITHIN THE ALBORAN SEA

by

Arthur R. Miller

Associated Scientists at Woods Hole, Inc.

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As background to this paper on Levantine Intermediate Water in the Alboran Sea I wish to comment on an article published in Science (AAAS) on the twelfth of November, a few weeks ago, which briefly discusses recognized changes in deep water properties of the North Atlantic Ocean. This article points out that the deep water has apparently remained historically constant, as expected, but, following the year 1972, some remarkable changes have occurred. "----since the GEOSECS Survey of 1972 water in the far northern North Atlantic has become 0.02‰ less saline and 0.15° C. colder." Even now, in a report being presented in San Francisco, Roemmich and Wunsch of Scripps and Woods Hole, respectively, are pointing out that, more than two decades after International Geophysical Year, observations of deep Atlantic water compared with those made in 1957 and 1959 along the latitudes of 36° N. and 24° N. have changed noticeably. They are reporting that "water between 500 and 3000 meters depth is warmer by as much as 0.2° C. However, above 500 meters and below 3000 meters water has tended to be cooler."

In the first figure (Figure No. 1) I am showing the deep salinity distribution across the North Atlantic Ocean from the Atlas of Worthington and Wright. This is the distribution across the 4° C. potential temperature surface. It demonstrates the widespread influence of Mediterranean water throughout the

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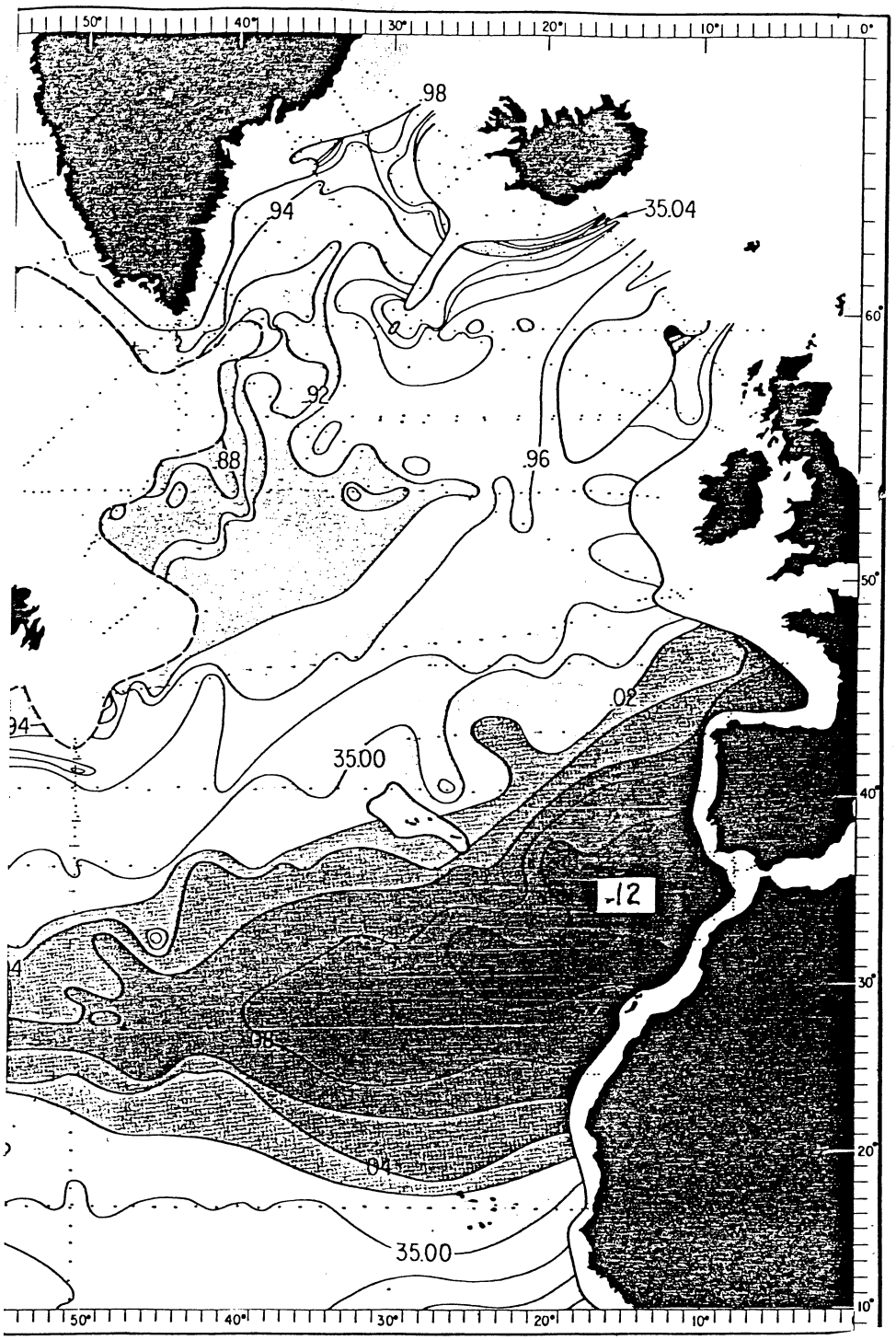


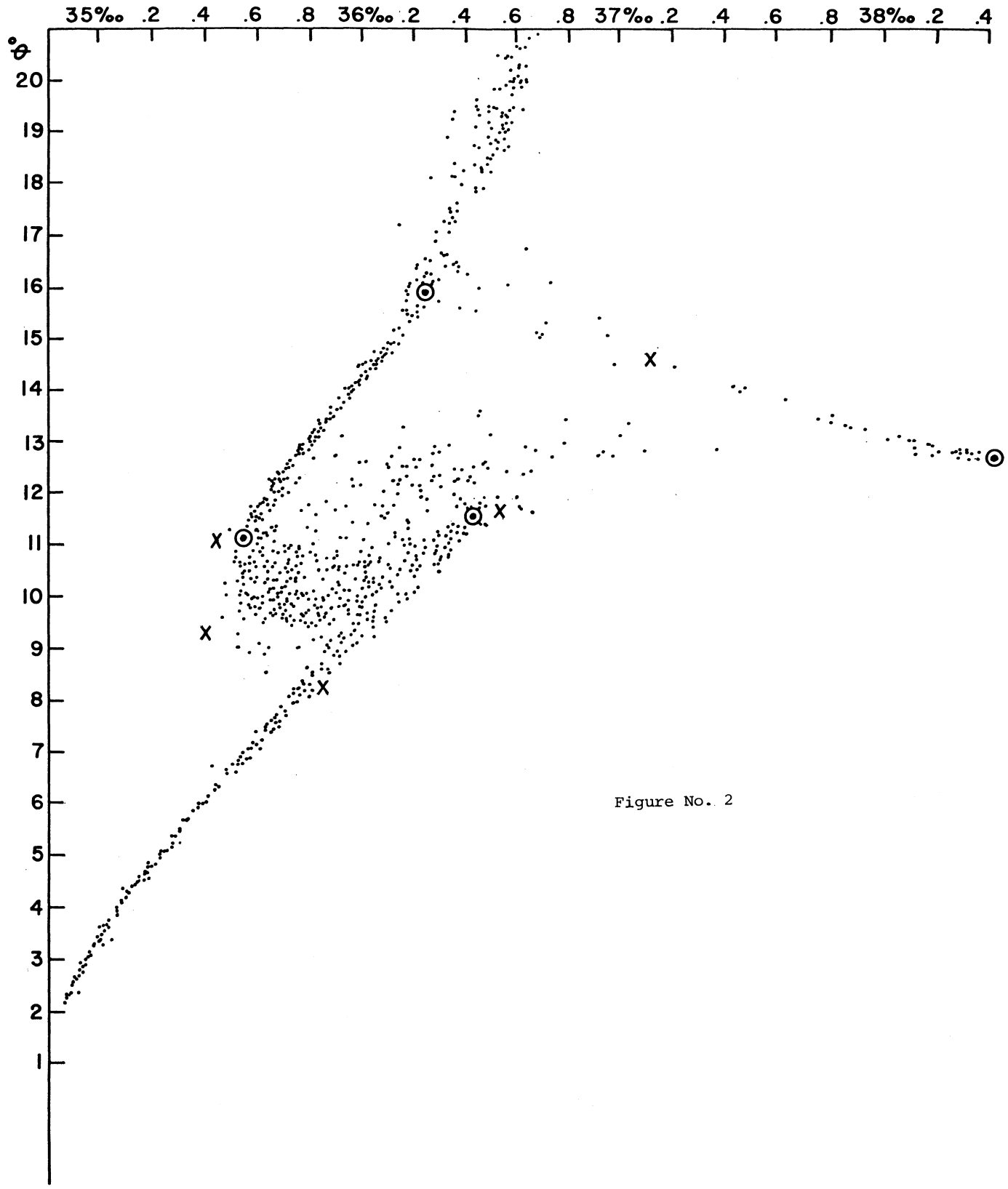
SALINITY (°/$_{oo}$) AT THE 4.0°C POTENTIAL TEMPERATURE SURFACE

Figure No. 1

Atlantic during the International Geophysical Years. The value of salinity at or near the approaches to the Mediterranean Sea is 35.12 ‰. The next diagram (Figure No. 2) describes the individual observations, for that time, in the Bay of Cadiz by means of a T/S coordinate system where the IGY observations have been corrected for pressure.

Comparison of this diagram with the Atlas distribution shows that at 4° Θ potential temperature the salinity value is consistent for the entire Bay of Cadiz area at 35.12 ‰. The sets of values plotted in Figure No. 2 also include observations from the Alboran Sea, east of the Strait of Gibraltar. All values cluster in a systematic pattern. For instance, the deeper observations from 11.6°/36.45 ‰ down to 4.0°/35.12 ‰ cluster along a straight line with a narrow spread probably limited only by analytical technical abilities. With the 4° water already Mediterranean in character, the straight-line distribution upwards to warmer water demonstrates even stronger Mediterranean influence, with a singular source at the point of inflection at 11.6°/36.45 ‰. There are no observations to the right of this line, hence this inflection point could be considered as the local source for Mediterranean-type water affecting the deep Atlantic.

At 11.1°/35.56 ‰ there is no Mediterranean influence. This is the North Atlantic Salinity Minimum Water which is generally found at 500 meters depth throughout the North Atlantic Ocean. It is probably no coincidence that this point, along with the inflection point at 11.6°/36.45 ‰, and the Alboran Sea Water at 13.0°/38.45 ‰ describe three points along a straight line. This occurrence suggests a mixing process consisting of only two sources, the North Atlantic Salinity Minimum and Alboran Sea Water. There are no observations below this line to the right of the inflection point. The fixed position of this inflection point among the other observations in the Bay of Cadiz signifies that the water usually described as Mediterranean water in the North Atlantic is actually a mixture consisting, at a maximum, of only 30% of pure Mediterranean water and 70% of North Atlantic Salinity Minimum (NASM). With such strong proportions of NASM water masking as Mediterranean water in the deep regions of the Atlantic vertical transport processes must be strong in the eastern North Atlantic in Mediterranean latitudes.


35‰ .2 .4 .6 .8 36‰ .2 .4 .6 .8 37‰ .2 .4 .6 .8 38‰ .2 .4
°θ
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18
17
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13
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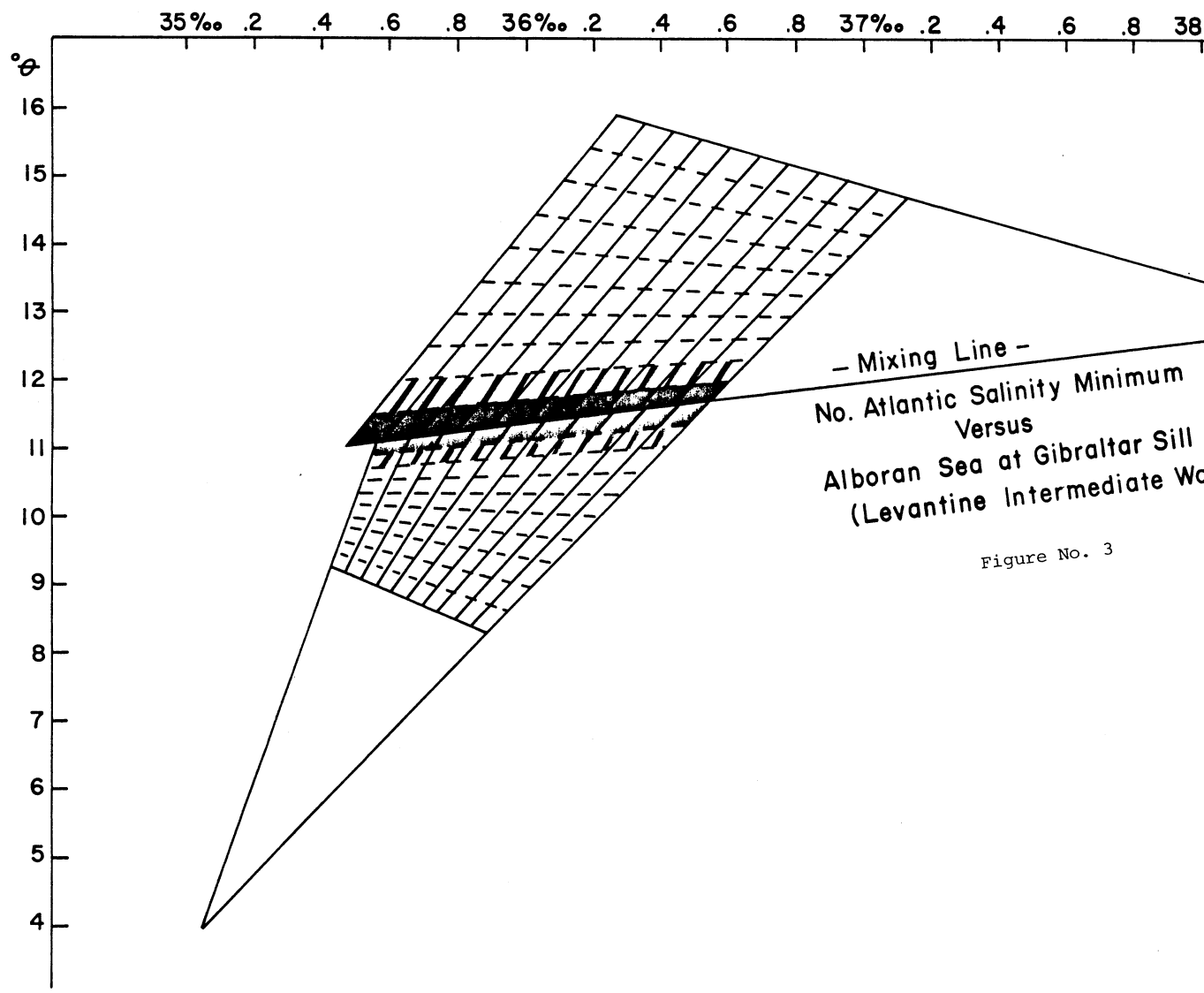
1

Figure No. 2

The next diagram (Figure No. 3) is a grid pattern enclosing the central core of observations from the previous T/S diagram. It is used as a tool to depict the water-type distribution in the Bay of Cadiz. Within a narrow strip which can be defined as simple mixtures between Salinity Minimum values and Mediterranean Inflection values it may be possible to construct the paths of strongest Mediterranean influence in the waters of the Bay of Cadiz.

The following diagram (Figure No. 4) making use of the grid shows that pure Atlantic water from the depth of the Salinity Minimum and upwards approaches the Gibraltar Sill without adulteration. At the sill mixing takes place. At 500 meters there is a levelling off of mixtures of Salinity Minimum and Mediterranean water. The more saline of these mixtures are transferred to deeper depths. The maximum effects are concentrated primarily at 800 meters and secondarily at 1200 meters.

The ultimate Mediterranean source of this mixing phenomenon is a singular water type described as the paired values of $13.0^{\circ}/38.45‰$ representing the westernmost Levantine Intermediate Water (LIW). LIW has its origins near Rhodes and Cyprus in the Eastern Mediterranean and maintains its continuity throughout the Mediterranean as it migrates westward. In the Alboran Sea, LIW layers are found generally between 300 and 400 meters depth. An example of this disposition is shown in Figure No. 5, an enlarged T/S diagram, where ATLANTIS Station No. 6009 is plotted in the central part of the figure. Levantine Intermediate Water is contained in that part of the water column described by a secondary temperature maximum (300 meters) and a salinity maximum immediately below (400 meters). The salinity maximum value, 38.45‰, represents the average salinity for all Mediterranean water determined from volumetric distributions. If the Mediterranean is to remain stable in time the excess salt concentrated by evaporation needs to be carried out of the system. LIW is probably the main artery by which excess salt is removed from the body of Mediterranean water but there may be other paths as well. General distributions of Western Medi-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°θ
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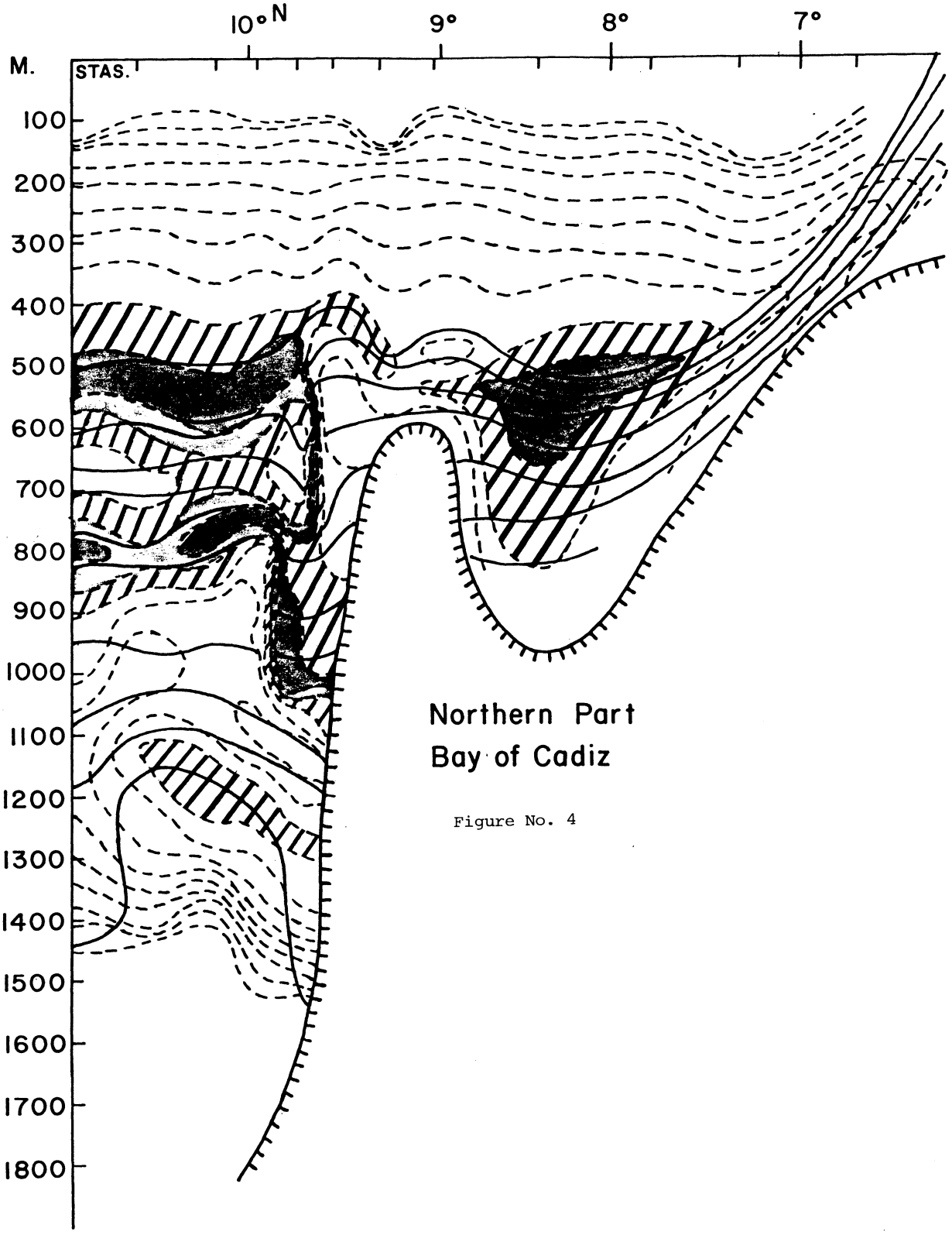
– Mixing Line –
No. Atlantic Salinity Minimum
Versus
Alboran Sea at Gibraltar Sill
(Levantine Intermediate Wa

Figure No. 3


10° N
9°
8°
7°
M.
STAS.
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200
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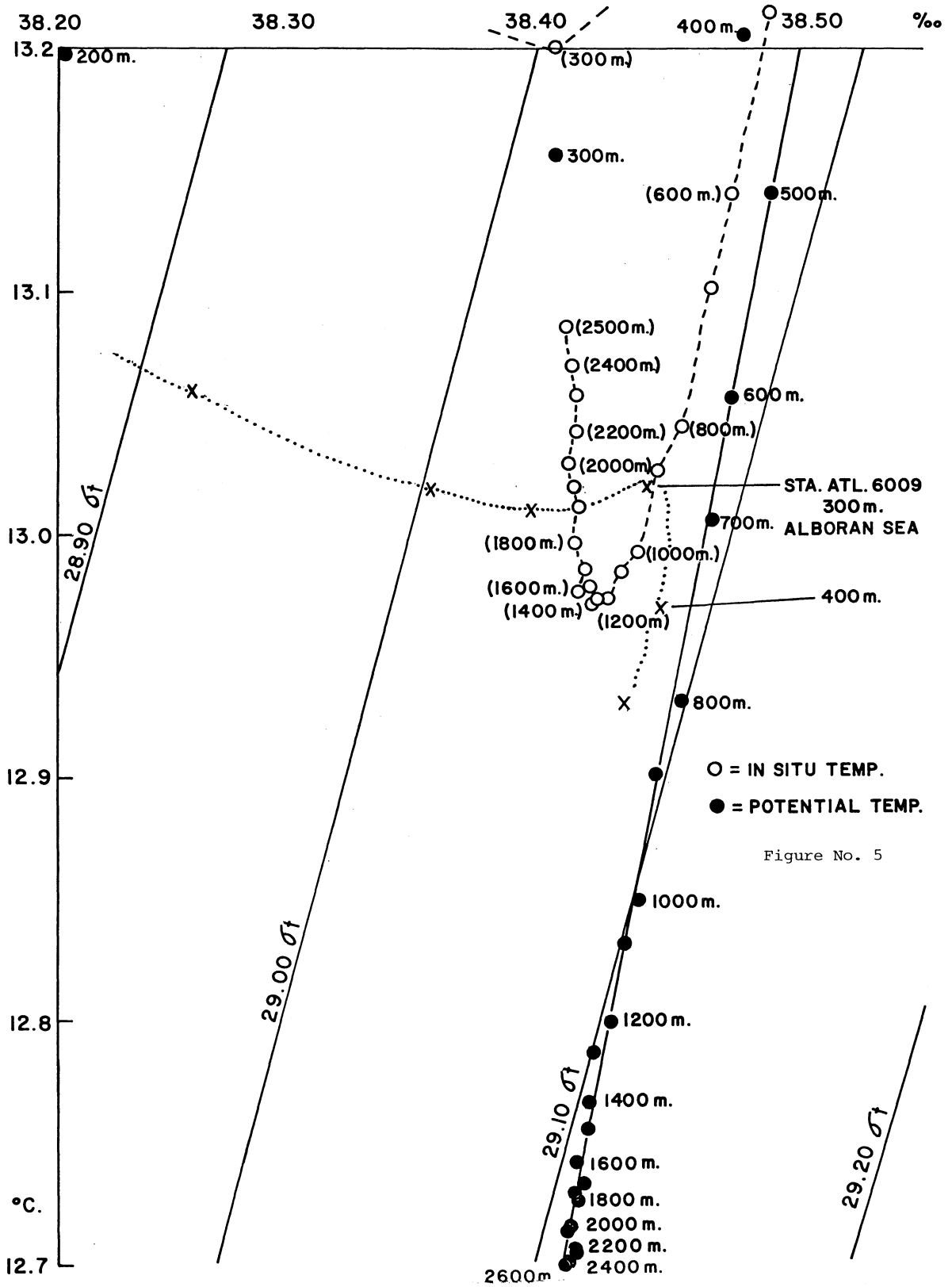
1200
1300
1400
1500
1600
1700
1800
Northern Part
Bay of Cadiz

Figure No. 4


38.20
38.30
38.40
38.50
‰
13.2
13.1
13.0
12.9
12.8
12.7
°C.
200m.
(300m.)
400m.
300m.
(600m.)
500m.
(2500m.)
(2400m.)
600m.
(2200m.)
(800m.)
(2000m.)
STA. ATL. 6009
300m.
ALBORAN SEA
700m.
(1800m.)
(1000m.)
(1600m.)
(1400m.)
(1200m.)
400m.
800m.
O = IN SITU TEMP.
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1200m.
1400m.
1600m.
1800m.
2000m.
2200m.
2400m.
2600m
28.90 σt
29.00 σt
29.10 σt
29.20 σt

Figure No. 5

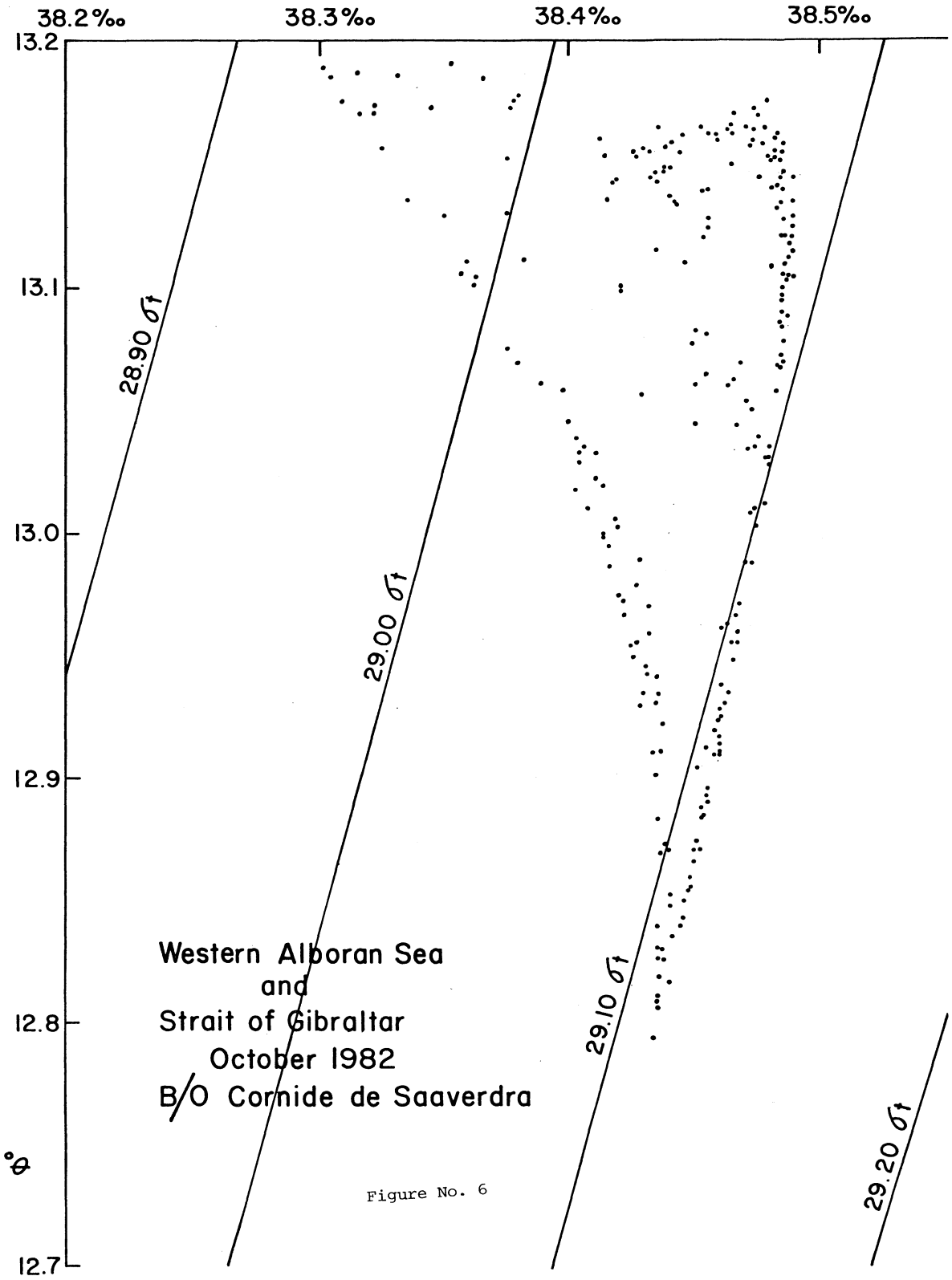
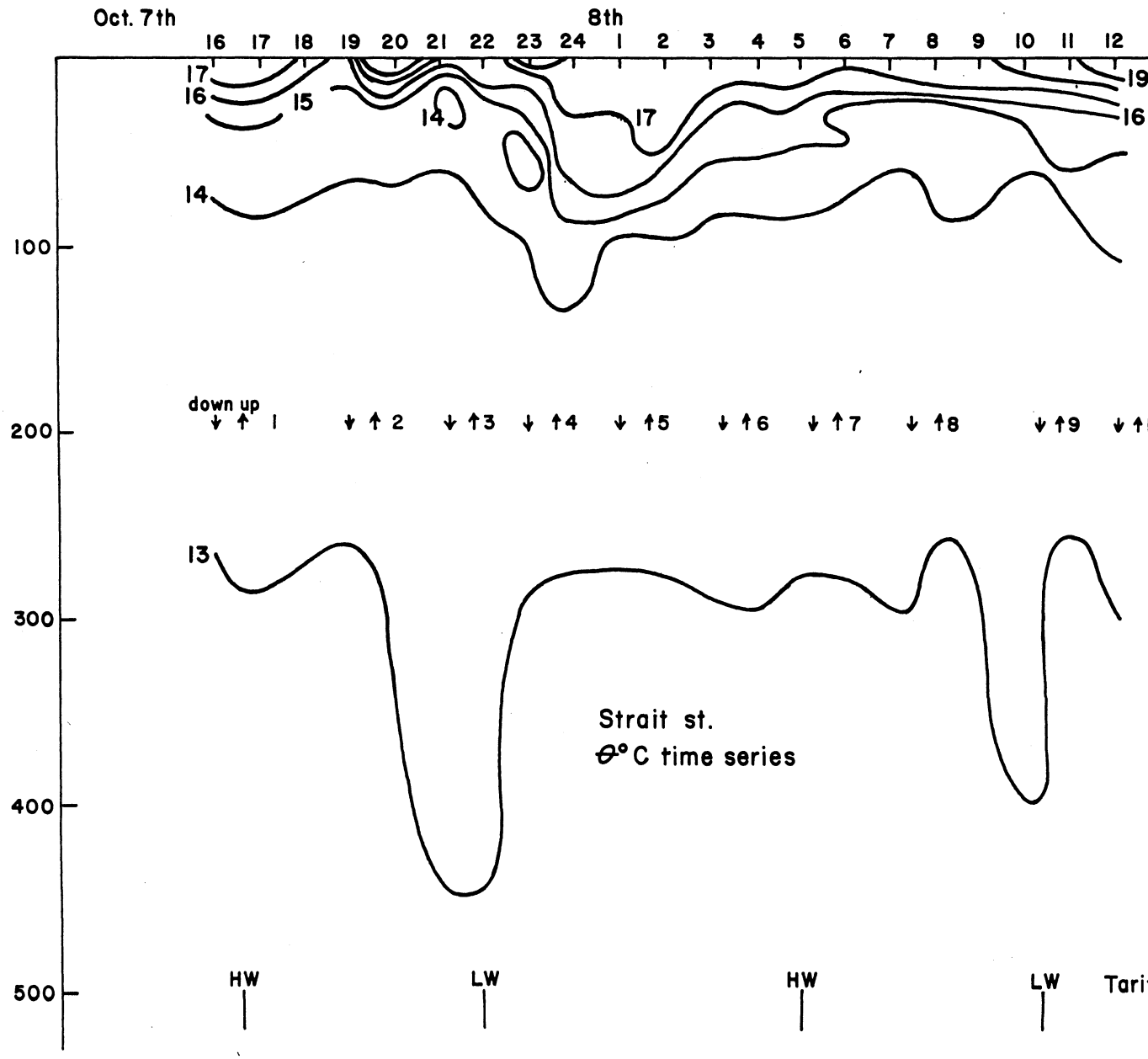

38.2‰
38.3‰
38.4‰
38.5‰
13.2
13.1
13.0
12.9
12.8
12.7
°θ
28.90 σt
29.00 σt
29.10 σt
29.20 σt
Western Alboran Sea
and
Strait of Gibraltar
October 1982
B/O Cornide de Saaverdra

Figure No. 6


Oct. 7th
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HW
LW
500

terranean water properties, typified in the rightmost distributions of Figure No. 5, show that water from the layers between 800 and 1000 meters can also serve as source water-type to mix with Atlantic water.

In the next diagram (Figure No. 6), similar to the previous one, recent observations from the Donde Va exercise in the Alboran Sea (October, 1982) are plotted. Levantine Intermediate Water is in the immediate surroundings of the eastern approaches to the Gibraltar Strait. Within the Strait itself there were two modes of distribution. In the series of stations taken by the Spanish research vessel Buque Oceanografico CORNIDE DE SAAVEDRA while in the Strait of Gibraltar Levantine Intermediate Water appeared to be by-passed and excluded from the mixing process. The fresher set of observations as shown in the diagram described a direct line to Alboran Sea water at 900 meters with T-S characteristics of approximately 38.45‰ and 12.8 or 12.9° potential temperature. However, at certain tidal stages Levantine Intermediate Water replaced the deep water and overshadowed any connection with deep water. This warmer water was particularly evident during predicted low waters at Tarifa. This is demonstrated in the temperature time-series for the Strait of Gibraltar (Figure No. 7).

The separation of at least two decades in time between the data shown in Figure No. 5 and Figure No. 6 point to the original question raised earlier in this paper about deep water changes in the North Atlantic. It appears that the outgoing Mediterranean water has passed through changes of similar magnitude as those noted for the deep Atlantic. Levantine Intermediate Water at the entrance to Gibraltar Strait has become warmer by about 0.15° C. and saltier by about 0.03‰. The values pertaining to water affecting the Atlantic are not too clear because of the implied participation of Alboran Sea deep water. In general, regardless of the bi-modal outflow, it seems that Alboran Sea deep water has become saltier than the IGY decade with an overall increase of 0.01‰.