International Hydrographic Review, Monaco, LXV(2), July 1988

OCEANOGRAPHIC STUDY IN FOUR SECTIONS OF THE STRAIT OF GIBRALTAR

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Summary

From thirty-four CTD stations obtained in the Strait of Gibraltar during 1986, the different water masses are separated according to their salinity, potential temperature and potential density characteristics. It is clear that the surface Atlantic inflow into the Mediterranean enters on the south side of the Strait while the Mediterranean outflow has a tendency to exit deeper on the northern side. This is evident principally at the sill.

INTRODUCTION

To understand the dynamics of flow through the Strait, a scientific project named 'Gibraltar Experiment' (BRYDEN and KINDER, 1986) was created which included an oceanographic cruise on board B/H *Tofiño* to make CTD measurements (RUIZ et al., 1986). The CTD data in the Strait has been analyzed and the results are presented here.

METHODS

From 18 to 22 October 1986, thirty-four CTD stations were made from the B/H *Tofiño* with a new Neil Brown Smart CTD (conductivity-temperature-depth) in the area shown in Figure 1. The navigation system was radar, the maximum depth of the cast was 600 metres. If the water depth was shallower than 600 m the CTD was brought to a depth 30 m above the bottom.

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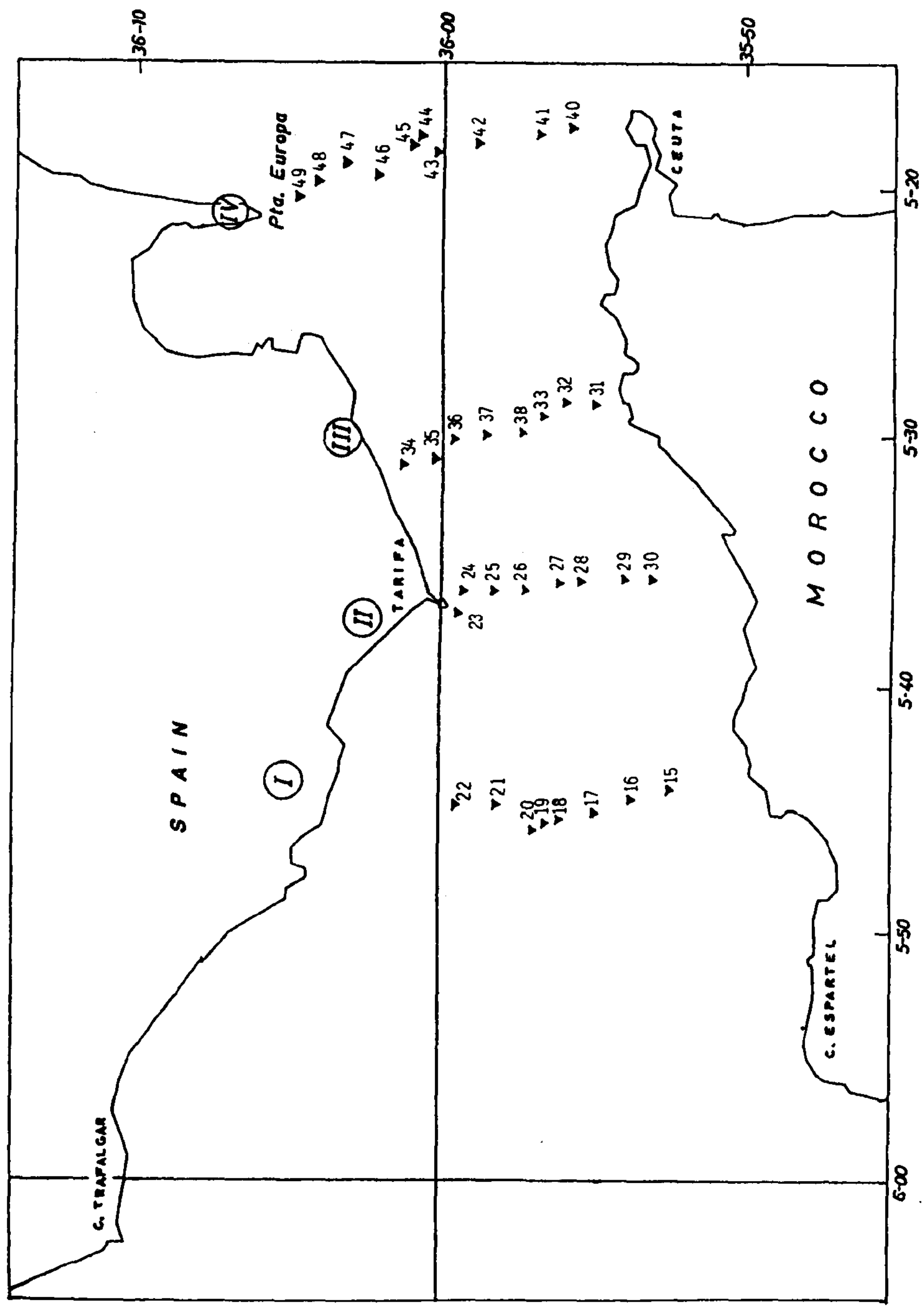

FIG. 1. — Stations situation.

The stations were subdivided into four sections: the first (stations 15 to 22) is at the sill, made in the time between four hours after a High Water until four hours before the next High Water; the second section (stations 23 to 30) crosses the Strait south of Tarifa, made from two hours before until five hours after the one High Water; the third (stations 31 to 38) is the Cires section, from Low Water until one hour after the next High Water; and the fourth section (stations 40 to 49) between Gibraltar and Ceuta, made from four hours after a High Water until two hours after the next High Water.

These stations were processed at the Woods Hole Oceanographic Institution with procedures described by FOFONOFF, HAYES and MILLARD (1974). There were no water samples for the calibrations, so two different methods of calibration were investigated. The first one was comparison of salinity values at $\theta = 12.87$ (BRYDEN et al., 1978) and the other one was the analysis of distribution of the θ values versus salinities 37.8‰ and 38.0‰. No distinguishable trend in the CTD data and no substantial differences from historical data were found, so that no changes were made to the original data. For the geostrophic velocity calculations (Table 1) the reference level was chosen to be the mean depth of the 37.5‰ isohaline.

Table 1

Geostrophic velocity in the Strait sections (cm/s)

Sections	I	II	III	IV
Stations	21-17	25-28	36-32	48-41
Depth				
0	399	528	140	60
50	335	409	153	65
100	131	161	100	24
130	0	0	22	0
140	-44	-50	0	-7
150	-88	-94	-20	-15
200	-301	-247	-100	-46
300	—	-363	-130	-57
400	—	-381	-133	-62
500	—	—	-136	—

DISCUSSION

For the determination of different water masses and the interface between Atlantic and Mediterranean waters, profiles were made of salinity, S, potential temperature, θ, and potential density, σ_θ, for each section.

In agreement with various authors (BOYCE, 1975; LANOIX, 1974; LACOMBE and RICHEZ, 1982), the values of σ_θ = 27.0, 28.0 and 29.0 were taken for separation of four water mass groups; for σ_θ less than 27.0, the water is undiluted North Atlantic Central Water (NACW). From 27.0 to 29.0 there is a mixture of Atlantic and Mediterranean waters with the σ_θ = 28.0 isopycnal marking 50 percent of each water mass and with proportionally increasing NACW percentage for lower σ_θ. Values greater than 29.0 indicated Mediterranean water, either Levantine

Intermediate (LIW) (maximum salinity and potential temperature) or Deep Water (DW)m ($\sigma_\theta \geqslant 29.10$, $\theta \leqslant 12.0$) (BRYDEN and STOMMEL, 1982).

Section IV (Fig. 1) occupies the eastern entrance of the Strait, between Gibraltar and Ceuta, exhibiting a maximum bottom depth of 900 m but with data only in the upper 500 m. A thin NACW layer slightly enlarged to the south was observed at the surface, with its depth increasing markedly in mid-Strait between stations 45 and 44; in the layer of mixed waters the predominant water is Mediterranean (Fig. 2). Below a mean depth of 250 m the water is completely

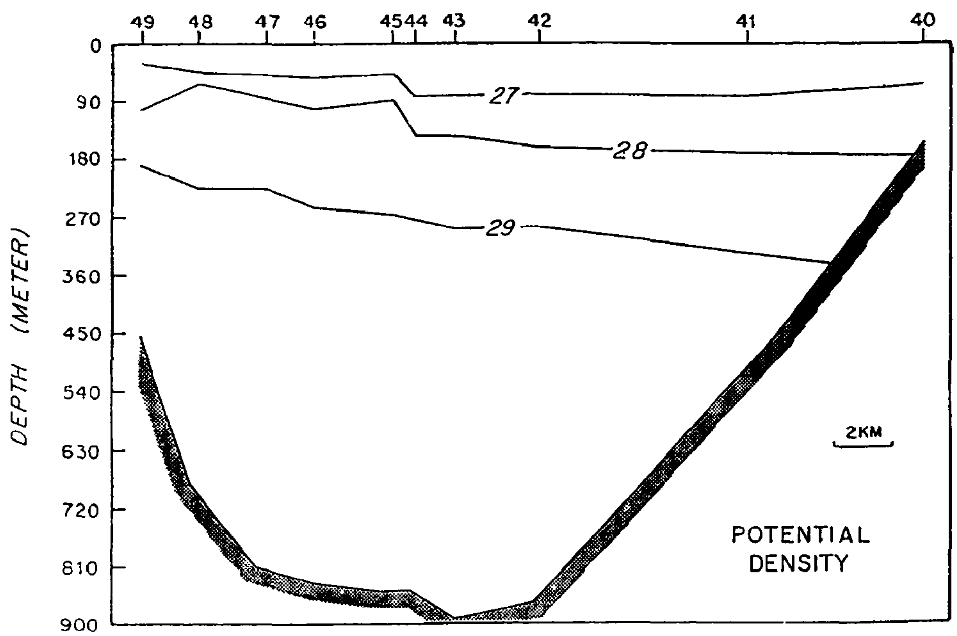

FIG. 2. — σ_θ in Section IV.

Mediterranean water. There are many salinity and temperature inversions; most of all for $\theta < 13$ and $S‰ > 38.43$ (Fig. 3a and b). The interface between Atlantic and Mediterranean water ($\sigma_\theta = 28.0$, BOYCE, 1975) changes from 60 m in the north (station 48) to 170 m in the south (station 41) with a 0.3° mean slope.

Section III (Fig. 1), the Cires section across the narrowest part of the Strait, has much less area than section IV, although its maximum depth of 900 m equals that of the Gibraltar-Ceuta section. To maintain the flow in and out of the Strait requires an increase in the geostrophic velocity (Table 1) and hence in the slope of the density surfaces. On this section, the NACW layer increases its depth to the south, lessening the mixed water area (Fig. 4). The sharp increase in depth again occurs in mid-Strait at station 38 and then increases more slowly to the south. Below 250 m mean depth, the water is completely of Mediterranean type. The mean transversal slope is 0,5°, and the interface depth ($\sigma_\theta = 28.0$) varies from 70 m (station 35) in the north to 190 m (station 31) in the south.

Section II crosses the Strait south of Tarifa (Fig. 1). In relation to the previous sections, the maximum depth has decreased by 30 percent to 640 m and

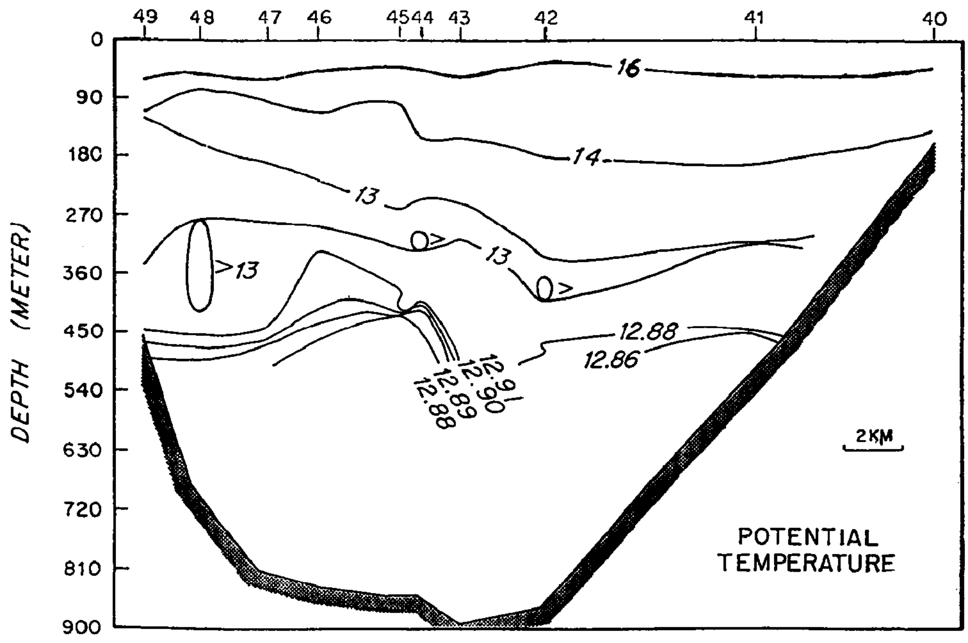

FIG. 3 a. — θ in Section IV.

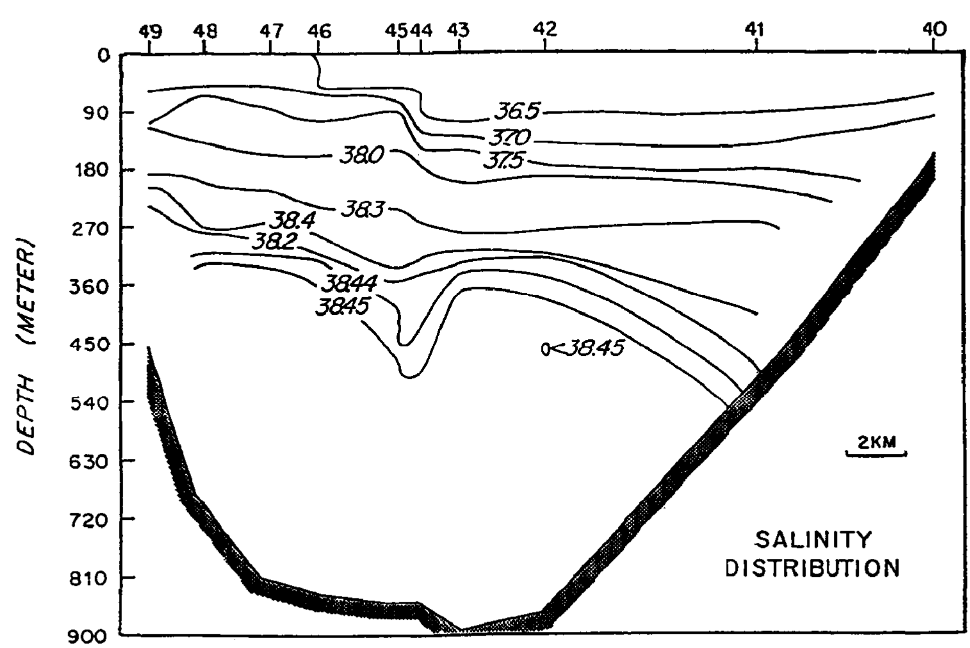

FIG. 3 b. — S‰ in Section IV.

so the Mediterranean water area has decreased significantly. There is a large increase in the geostrophic velocity (Table 1) indicating stronger slope of the interface across the Strait. The NACW layer is substantial on the south side of

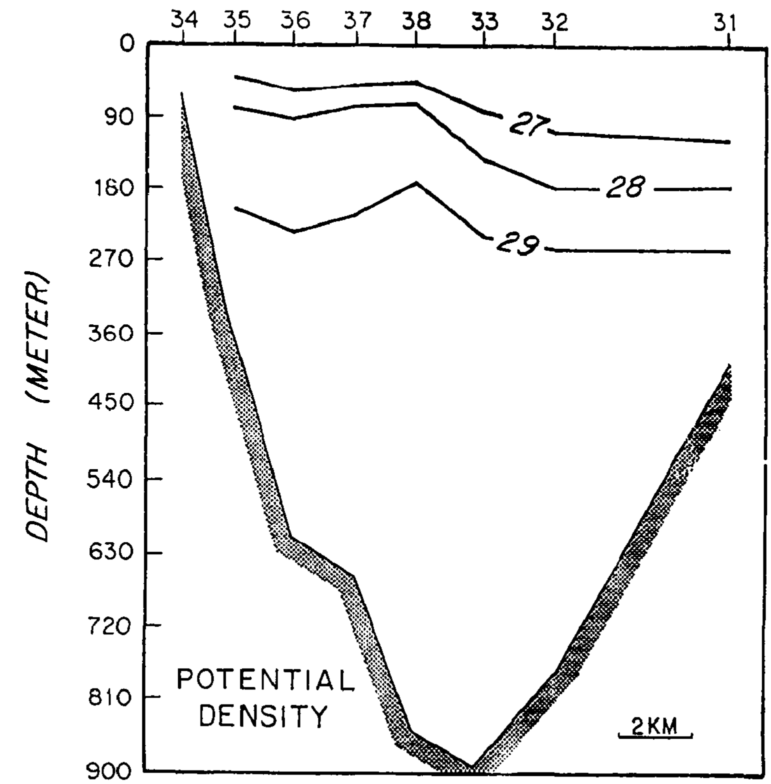

FIG. 4. — σ_θ in Section III.

section II. Station 27 in mid-Strait (Fig. 5) marks a sharp change in the pycnocline and the undiluted Mediterranean water on the south side of the section is drastically diminished. On the north side of this section, the thin NACW is much less than in the previous section, but the mixed and undiluted Mediterranean water regions are similar to the previous section. The mean transversal slope along the section is 1.2° and also interesting is the slope between stations 27 and 28 where the isotherms and isohalines exhibit a large change with a slope of 8.2°.

Section I (Fig. 1) corresponds to the sill of the Strait of Gibraltar where theoretical hydraulic control models for the Strait are taken to be critical (BRYDEN and STOMMEL, 1984). South of station 19, the NACW layer occupies more than 70 percent of the area. Continuing in depth, Atlantic diluted water and Mediterranean diluted water cover the undiluted Mediterranean water which is very thick on the north side and totally absent on the south side of the Strait (Fig. 6). In station 17, there is a great inversion in salinity and temperature (Fig. 7a and b) about 40 m above bottom with $S = 36.85‰$ and $\theta = 14.08$ corresponding to NACW diluted flow at high velocity into the Mediterranean Sea. North of the sill (which is at station 19) the detected water in the lowest 40 m is Levantine Intermediate Water. Undiluted Deep Water flow on the sill section was not detected.

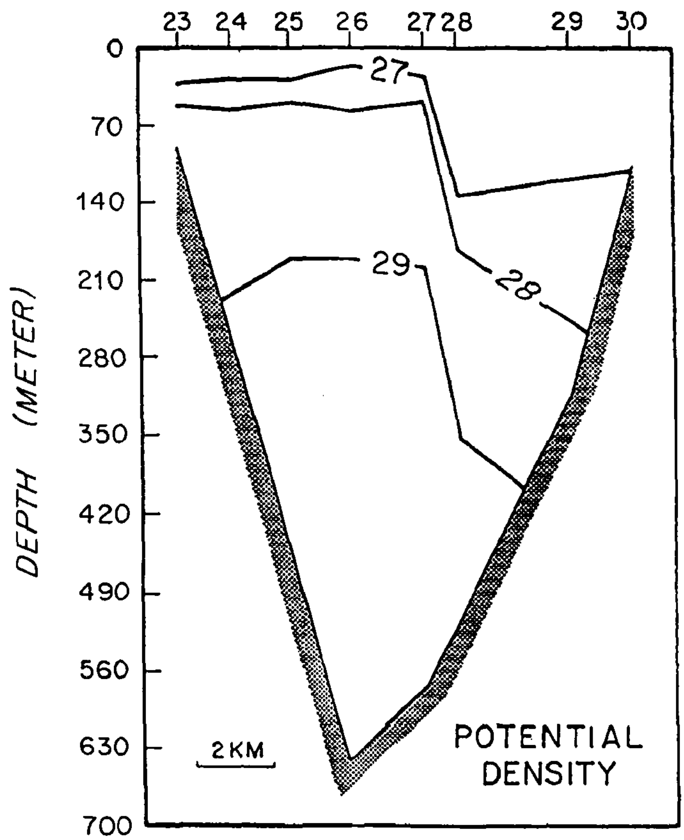

FIG. 5. — σ_θ in Section II.

The calculation of mean transversal slope for the interface (σ_θ = 28.0), from 20 m at station 21 in the north to 260 m at station 17 in the south, has a value of 1.4° which represents the greatest value in all sections.

CONCLUSION

From the data, taken over five days, there is clear evidence of the Coriolis effect in the Strait of Gibraltar. In the southern half, it is characteristic to observe principally Atlantic inflow water. On each section there is a marked change in depth of the Atlantic layer at stations 45-44, 38-32, 27-28, 19-18 (Fig. 1) which are all in mid-Strait. South of a hypothetical line joining these stations, Atlantic water dominates the water column. Also the Coriolis effect forces the outflowing Mediterranean water to be north of this hypothetical line. The Mediterranean water banks from mid-section up onto the Spanish continental slope.

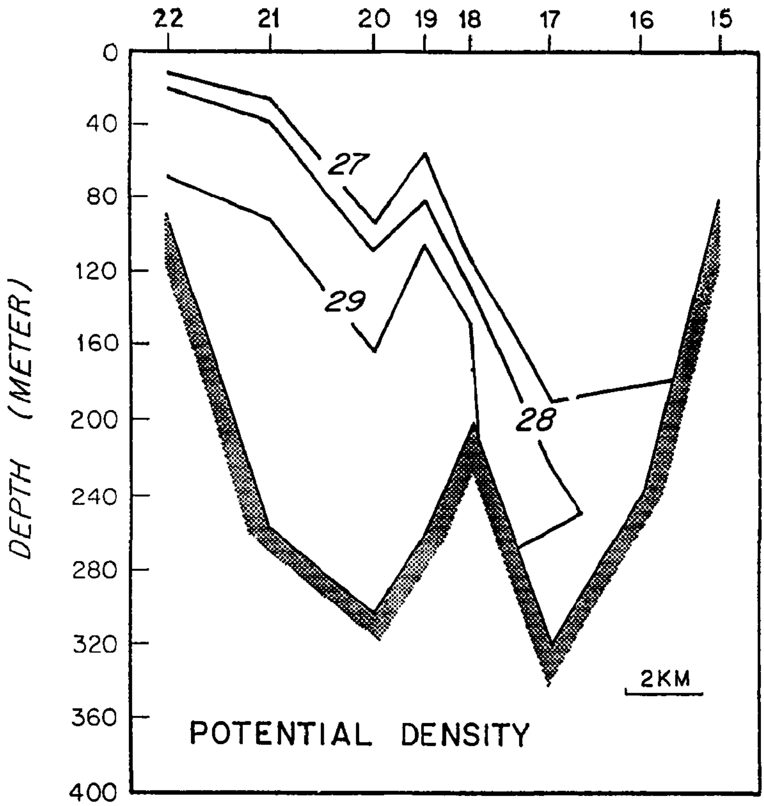

FIG. 6. — σ_θ in Section I.

The Deep Water signal decreases from the Gibraltar section to the west and was not detected at the sill. In the same way, the interface between Atlantic and Mediterranean waters presents a transversal inclination whose slope is four times greater at the sill than at the Gibraltar section.

Acknowledgments

We wish to thank Maria del Carmen LACAVE ABARZUZA and Toshico TURNER for typing the manuscript and drafting the figures, respectively.

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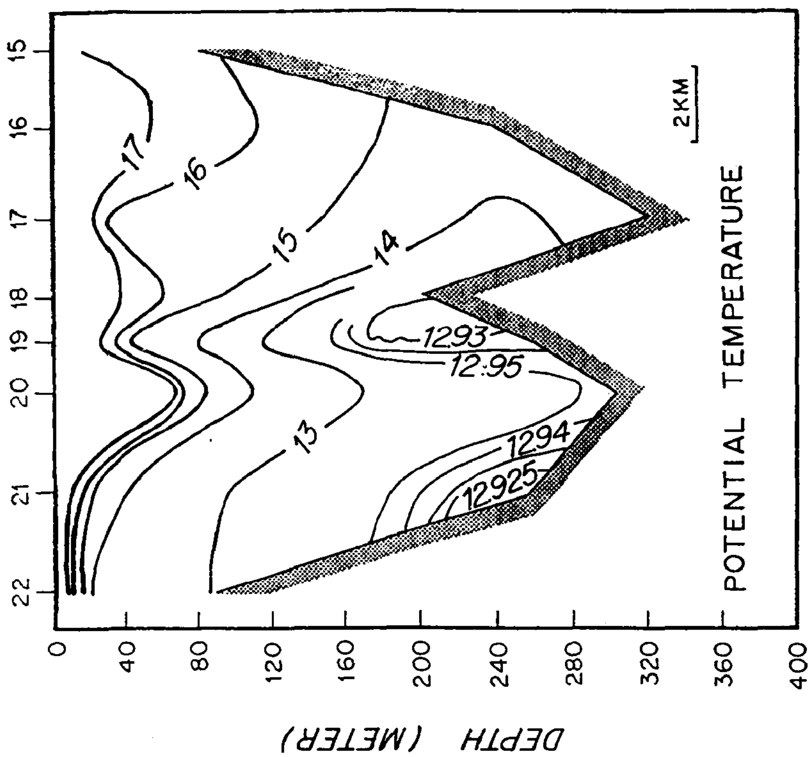

FIG. 7 b. — θ in Section I.

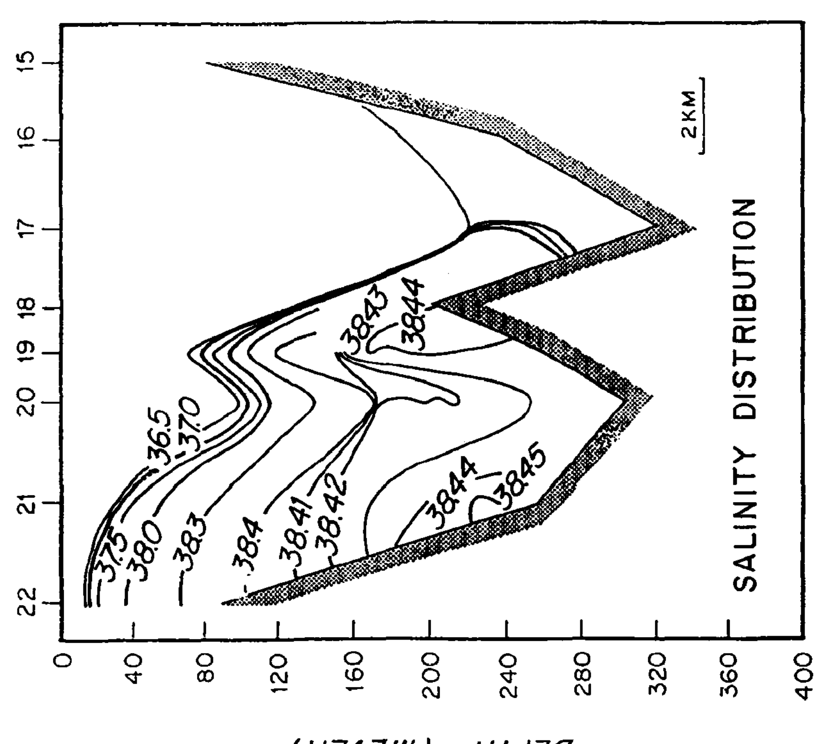

FIG. 7 a. — S‰ in Section I.

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