Deep variability in the Western Mediterranean Sea

by

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The Mediterranean Sea is a natural mechanism for increasing the salt content of Atlantic sea water and returning it to the Atlantic Ocean with increased density. Vertical movement is an integral part of the mechanism. Below the transient thermocline the vertical water structure in the Mediterranean is practically isopycnal considering its potential density. Adiabatic effects are strongly evident in deep water where observed temperatures increase markedly with depth below 1200 meters. The onslaught of winter storms and the combined effects of cooling and evaporation of surface waters are sufficient to increase surface density equivalent to the potential density of deep and bottom water.

In the west, sinking surface water mixes with and erodes the intermediate Levantine Water. Observed vertical transport is at least ten times greater than that observed in the Atlantic Ocean.

Observations from the Medoc cruises have shown that surface water can sink to depths of 2000 meters or more. With evaporation acting upon the surfaces of both the Eastern and Western Mediterranean Seas the subsequent salt concentration and storage in the sinking process at mid-depths and deep depths can be presumed to be increasing the salt content of the Mediterranean Sea at some more or less constant annual rate. The present analysis suggests that the removal of the annual salt accumulation comes about by way of cyclic vertical exchange within the water column. The water mass passing over the Gibraltar Sill consists of a mixture of both Eastern and Western origins in approximately equal proportions.

Historical data were used in a computer-averaged analysis of the Algero-Provençal Basin of the Western Mediterranean Sea. The computer was directed to screen all hydrographic data between the Greenwich Meridian and 9° East and from 35° North to 44° North. Also, the computer was instructed to note all maximum and minimum values within 100-meter intervals and totally the spatial distributions of hydrographic stations in each one-degree square of the area. The averaging was intended to determine the characteristic parameters for each 100-meter interval from the surface to 2500 meters, along with the standard deviation for each 100-meter block.

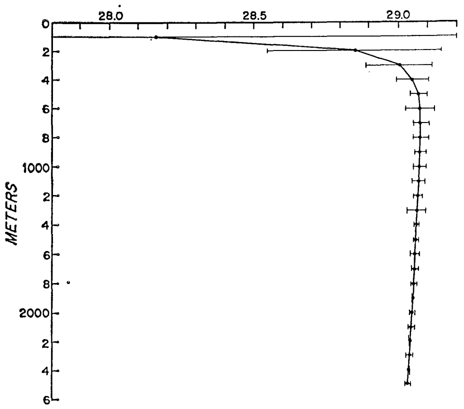

Fig. 1. — Average sigma t for the Western Mediterranean Sea with limits defined within one standard deviation.

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Ideally, each one-degree square needed to be evenly represented by data in time, space, and quality if bias were to be totally absent. In reality, each square was represented by five or more stations with a high concentration of 50 or more stations in the northern sector centering around 42° North and 5° East. Peak monthly activity occurs in the months of February, March and July, August with an average temporal distribution of about 100 stations per month. Historically, there were peaks of active sampling centering on the years, 1912, 1922, 1930, 1949, 1958, 1964, and 1969. From 1960 to the present, salinity values were determined by conductivity methods rather than by titration. Table 1 shows the overall average and seasonal mean values of potential temperature and salinity at 100- meter intervals.

Figure 1 is a plot of the average sigma-t density against depth together with the ranges of values representing one standard-of-deviation for each interval. The variances are extremely small, with the exception of the upper layers, implying a comfortable level-of-confidence in the average values. This is also the case with the averages of temperature, salinity, and, to a lesser degree, with oxygen. As many as 5000 to 6000 observations from more than 1300 hydrographic stations enter into the upper sets of values and from 200 to 400 in the deepest values. Because of uneven temporal distribution and of peak seasonal observations in winter and summer six-monthly averaging was done to reduce numerical bias at the expense of seasonal detail. However, the reduction of the number of observations for seasonal averaging gave *smaller* variances at all levels than the *total* averaging, indicating real seasonal trends.

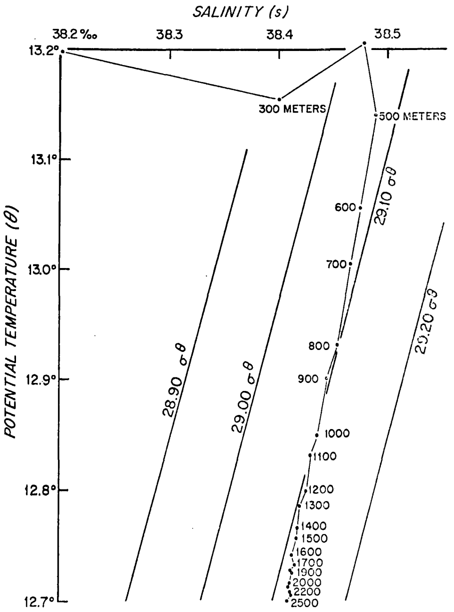

FIG. 2. — Temperature (Θ)/Salinity (S) distribution of averaged values for the Western Mediterranean Sea.

Figure 2 is a potential-temperature / salinity curve of the average values. Aside from the upper layers, 0 to 400 meters, all of these values fall along a straight line between the values, 12.672° C/38.397 ‰ and 13.200° C/38.500 ‰. (For simplicity, the 400-meter interval is assumed to take on the latter value although, in reality, it is slightly less saline.) The first pair can represent the condition found at the surface (5° E., 42° N.) in winter during a period of " turnover " and the second can represent Levantine Intermediate Water *resident* in the Western Mediterranean. An extension of this line in the warm/salt direction passes through the paired values, 14.5 ° C/38.8 ‰, which represent Sicilian sill-depth observations in the Eastern Mediterranean, the source of Levantine Intermediate Water entering the Sicilian channel.

With all the water in the Western Mediterranean below 400 meters adequately described by this straight line, the main water mass can be defined as a simple mixture with only two sources. Thus, percentage values may be assigned to the seasonal averages in terms of one or the other extremes and the vertical distributions examined against time. Percentile mixtures were defined in reference to the coldest and freshest deep water. This water (100 0/0 = 12.672° C/38.397 ‰) was also the approximate value of " preconditioned " surface " turnover " water observed in February, 1969 during the intensive Médoc investigations.

Figure 3 represents the percentages of " winter water " distributed with time and based on four seasonal averagings of six-month's span each. (The dashed line of the 85 % percentile is an alternative interpolation.) The cross-hatched area in the upper 200 meters does not fit within the " simple mixture " interpretation. Winter " turnover " water, because of its local origins, is masked out by the spatial average which takes into account the entire area from 0° to 9° East and 35° N. to 44° N. However, at 200 meters and below there is essentially no " noise " in the " simple mixture " concept. Minimal percentile values occur between 400 and 500 meters. This is the Levantine Intermediate layer. Above this, the greatest percentage of winter water occurs between November and February. Its diminution with time is marked by concurrent diminution of Levantine water and the appearance of more " winter water " on the bottom. It is coincident with the massive overturning reported by the Medoc Group. In April, May, and June, pure " winter water " makes a general appearance on the bottom. This delay probably represents the lateral dispersion of winter water as it spreads away from the area of origin and becomes more dominant within the averaging process. At this time, at all levels, the concentration of winter water is increased, particularly at lower depths, and Levantine water has diminished. There appears to be a greater seasonal fluctuation of percentage values the greater the depth.

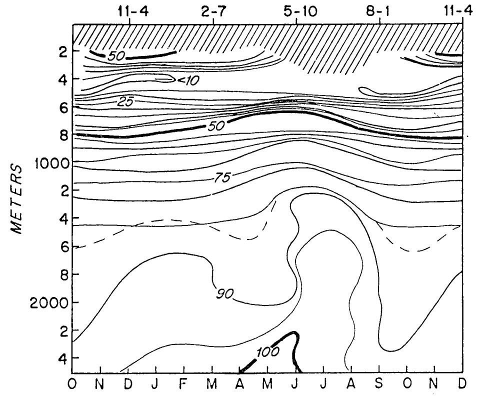

Fig. 3. — Seasonal variation of " Winter water " expressed in percentage distribution for the Western Mediterranean Sea.

Most of the Western Mediterranean Sea water is made up of proportionate combinations of locally-produced winter water and water from the Eastern Mediterranean, as represented by resident Levantine Intermediate Water. The volumes of the East and West basins are roughly comparable and, in order to maintain a long-term steady-state salt budget, proportionate amounts of high salinity water from each basin need to be drawn off into the Atlantic. Figure 4 is similar to Figure 2 but differs by the addition of *in situ* average values (See Footnote) and the plot of a representative station (Atl. 6009) for the Alboran Sea. These additions show that the 300-meter level in the Alboran Sea has the same temperature and salinity values as the average values for 900 meters in the Algero-Provençal Basin. This corresponds approximately to the 50 % mixture if the 900 m. (or 800 m.) temperature is adjusted adiabatically and represents water available at sill depth.

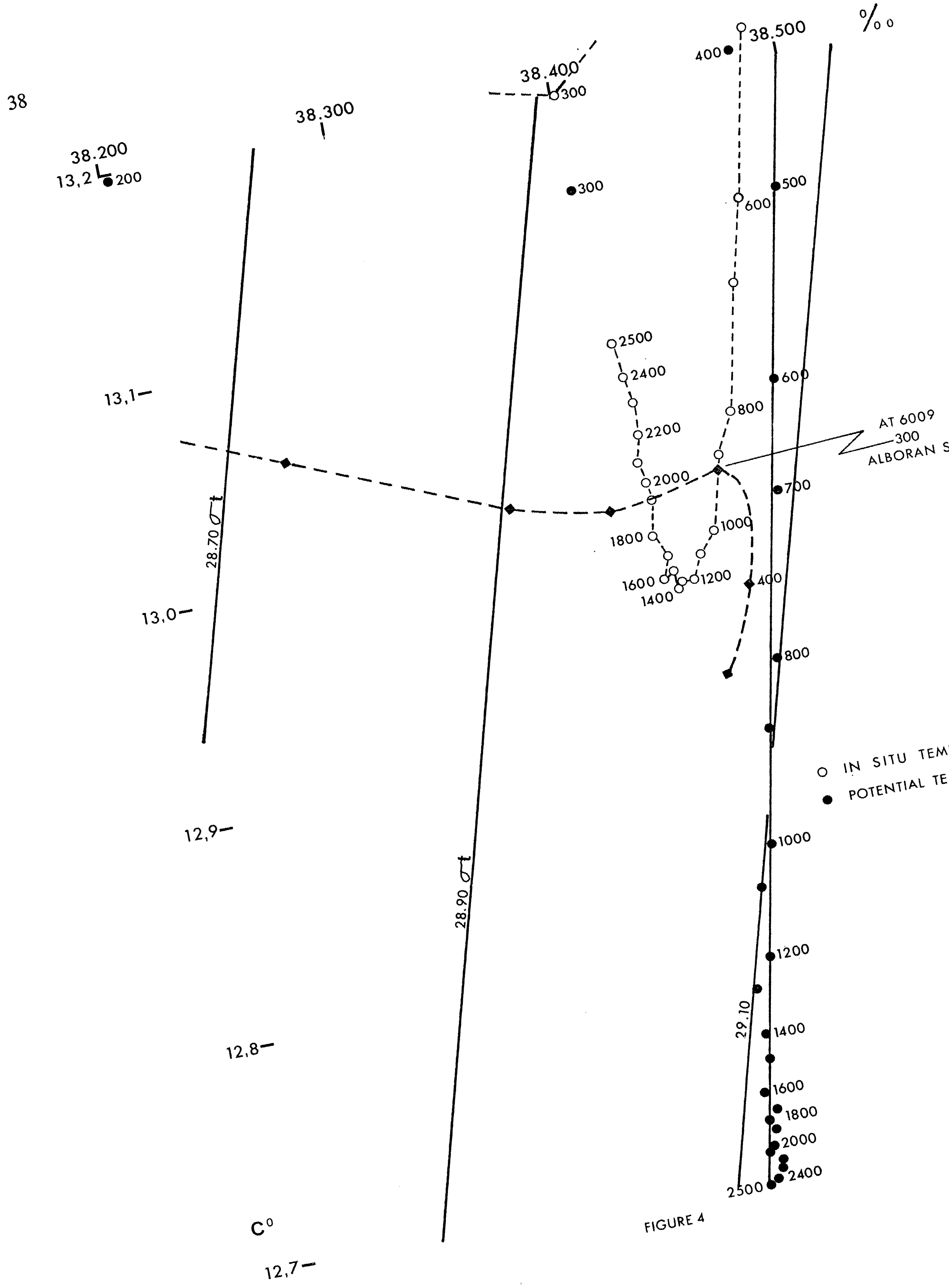
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FIGURE 4

Table 1.

Average values from observations of Potential Temperature (θ) and Salinity (S) from historical (archived) data in the area bounded by 35° N to 44° N and O° Greenwich to 9° E

Depth Interval	Total Average		Mo. 11-4		Mo. 2-7		Mo. 5-10		Mo. 8-1	
	θ	S	θ	S	θ	S	θ	S	θ	S
0–100 m.	15.150	37.897	13.266	37.976	14.221	37.923	19.048	37.734	17.858	37.820
–200	13.198	38.202	.135	38.230	13.145	38.213	13.404	38.109	13.383	38.163
–300	.155	.401	.150	.409	.144	.403	.184	.360	.207	.393
–400	.205	.477	.196	.479	.187	.473	.241	.466	.278	.491
–500	.141	.488	.136	.489	.127	.486	.166	.484	.202	.499
–600	.055	.473	.052	.475	.040	.472	.068	.466	.116	.476
–700	.005	.464	.020	.470	.003	.463	12.943	.441	.010	.467
–800	12.930	.453	12.933	.454	12.919	.450	.919	.448	12.970	.466
–900	.901	.443	915	.448	.903	.443	.846	.422	.894	.441
–1000	.849	.435	.853	.436	.843	.433	.830	.428	.870	.440
–1100	.831	.428	.839	.431	.834	.429	.796	.416	.822	.427
–1200	.798	.423	.803	.425	.797	.423	.772	.418	.801	.426
–1300	.786	.417	.791	.421	.788	.417	.770	.401	.782	.419
–1400	.765	.416	.768	.418	.764	.414	.752	.404	.768	.421
–1500	.755	.415	.755	.415	.754	.415	.755	.413	.757	.416
–1600	.741	.410	.744	.413	.742	.411	.735	.404	.740	.409
–1700	.732	.413	.735	.413	.728	.412	.675	.410	.740	.414
–1800	.727	.409	.727	.411	.725	.408	.726	.397	.730	.411
–1900	.725	.411	.724	.411	.724	.411	.736	.410	.726	.410
–2000	.715	.408	.716	.408	.713	.407	.709	.407	.721	.412
–2100	.713	.407	.713	.408	.713	.408	.717	.402	.714	.404
–2200	.707	.409	.710	.410	.703	.409	.662	.404	.714	.409
–2300	.705	.409	.707	.410	.701	.408	.660	.400	.715	.412
–2400	.700	.408	.704	.409	.695	.406	.676	.404	.711	.413
–2500	.699	.406	.700	.406	.696	.405	.672	.396	.705	.408

Oxygen values, averaged seasonally, appear to support a year-round erosion and re-supply of the Levantine Intermediate Layer with marked seasonal fluctuations. The outflow at Gibraltar removes the annual salt increment of both the East and West Mediterranean. Apparently the very deep waters of the Western Mediterranean need not participate directly in the Gibraltar overflow if, primarily, the vertical exchange below the Levantine Intermediate Layer, producing the 50 % mixture, is a continuing process.

Footnote : These average plotted *in situ* values should be useful for comparison with field observations.

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