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SHORT CONTRIBUTION

Tritium and oxygen profiles in the eastern Mediterranean

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ABSTRACT

The tritium and oxygen concentration profiles reported here were made in February and March 1974 and refer to the Straits of Sicily, the Ionian Sea, the Sea of Crete and the Levantine Basin. In the stations southeast of Rhodes and north of Crete, the most saline waters have the highest tritium concentrations, i.e. 10.5 ± 0.5 T.U. and 14 T.U., respectively. In the Ionian Sea and the Straits of Sicily, on the contrary, the tritium maximum lies above the salinity maximum, with values from 12 to 19 T.U.

The core of the Levantine Intermediate Water shows the same tritium concentration (about 10 T.U.) from the Levantine source regions as far as the central Ionian, suggesting a fairly high westward flowrate.

1. Introduction

The Mediterranean is divided into two main basins by the Straits of Sicily. The eastern part is referred to as a "concentration basin", where the amount of water lost by evaporation exceeds the amount gained by precipitation and river discharge. Two opposite flows connect the eastern and western basins through the Straits of Sicily. To compensate for the loss in the water balance, more water enters the eastern basin than flows out of it, and in order to keep the amount of salt constant, the amount of salt brought in by the entering flow must be equal to that of the outflow. Thus, the upper flow, moving towards the east, carries in more water of Atlantic origin of lower salinity than the deeper westward flow (Levantine Intermediate Water), which is characterized by a salinity of about 38.7‰ and a temperature of about 14 °C. After passing the western sill in the Straits of Sicily, the L.I.W. descends to a level of stability at a depth of about 600 m in the Tyrrhenian Sea. It originates in the North Levantine Basin where, as a result of enhanced surface cooling and evaporation during winter, dense water masses are formed which sink and spread westwards.

The radioactive hydrogen isotope tritium, having a half-life of about 12.2 years, is constantly produced by the interaction of cosmic radiation with atmospheric oxygen and nitrogen and enters the oceans as HTO both in rain and by molecular exchange on the surface. However, the amount of tritium naturally produced in the atmosphere is small in comparison to the very much larger amounts that were injected into the stratosphere by nuclear weapons from 1954 to 1962. Since the beginning of the nuclear tests the seawater tritium concentration has varied with time, as the tritium content in ocean waters prior to the bombs ranged from zero to about 1.0 to 1.5 T.U. (Bainbridge, 1963; Taylor, Polach and Rafter, 1963).

2. Analytical techniques

In the hydrographic casts, a Rosette sampler with 1.7 l plastic Niskin bottles was used to collect the samples for tritium and oxygen analyses. The tritium measurements were made according to the

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method described by Cameron (1967): the water samples are distilled; 250 ml of the distillate are enriched by electrolysis until only 8–9 ml remain. The enriched sample (5 ml) is reduced by hot magnesium metal to hydrogen, which is then converted with ethylene on a Pd–asbestos catalyst to ethane. The ethane is then introduced into a low level proportional counter at a pressure of 1.9 atm.

The tritium concentrations are reported as tritium units (T.U.) that is, the number of tritium atoms relative to 10^{18} hydrogen atoms. The accuracy of the measurements is about ± 0.8 T.U. The Winkler method was used for the dissolved oxygen analyses. The oxygen contents are given in per cent saturation, with an accuracy of $\pm 1\%$. The salinity analyses were made with an Autolab Salinometer.

3. Results and discussion

The water samples were collected at the stations shown in Fig. 1. The tritium and oxygen profiles for the Levantine Basin (stations 30, 46 and 77), the Sea of Crete (station 25), the Ionian Sea (stations 13, 16 and 20) and the Straits of Sicily (station 8) are shown in Fig. 2 along with the salinity profiles.

3.1. *Levantine Basin*

At station 46, the upper layer, about 150 m thick, showed uniform salinity, temperature, tritium and dissolved oxygen concentrations with values of 39.048 ± 0.08‰, 15.21 ± 0.06 °C, 10 T.U. and $96 \pm 0.6\%$ saturation, respectively, and with a mean $\sigma_T = 29.05 \pm 0.01$. This water is lighter than some observed in the northern part of the basin, but is denser than the upper layers in the west. Therefore, this layer may sink and move westward thus contributing to the L.I.W. flow which is fed mainly by water formed in the northern part of the basin (Ozturgut, 1976).

At station 30, the more saline layer (39.08‰, 15.92 °C, $\sigma_T = 28.9$) is found at 200 m depth, having tritium and oxygen content of 10.9 T.U. and 94.3% sat. These values are close (within the expected error of measurement) to those measured in the upper layer at station 46, and give evidence of sinking. Station 77 lies in the middle western part of the basin, where a cyclonic circulation exists (Ozturgut, 1976). In this area L.I.W. is probably formed, but not yet mixed. From the available data we may therefore assume a mean tritium content of about 10.5 T.U. and a mean oxygen per cent saturation of 95 (5.27 ± 0.1 ml/l) for the L.I.W. formed in the Levantine Basin. Unfortunately,

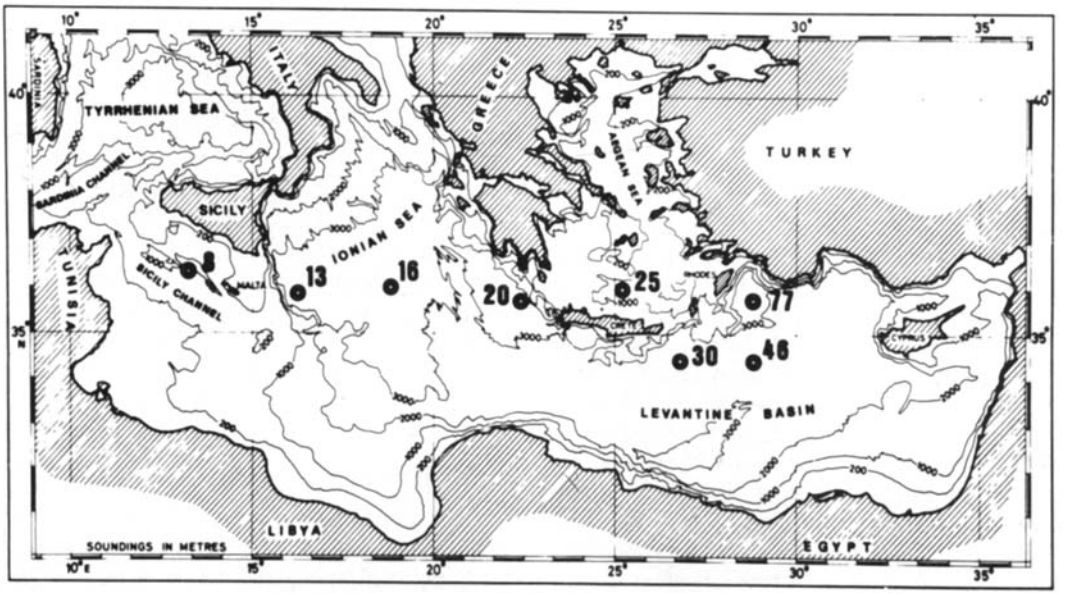

Fig. 1. Location of stations at which samples were collected.

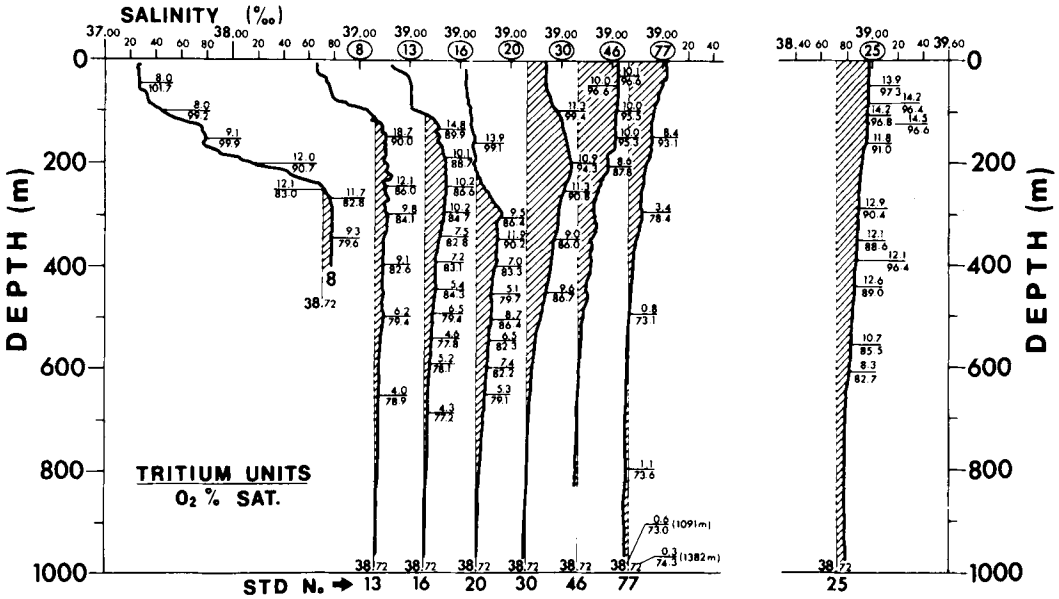

Fig. 2. Salinity, tritium and oxygen profiles in the Straits of Sicily (station 8), the Ionian Sea (stations 13, 16, 20), the Levantine Basin (stations 30, 46, 77) and the Sea of Crete (station 25). The station numbers are given at base of figure; the encircled station numbers along the top indicate the 39.00‰ salinity of the corresponding profiles.

there are relatively few data, some of which refer to stations that are not as representative as they might have been in good weather conditions.

3.2. *Sea of Crete*

At station 25 the very uniform temperature (14.95 ± 0.005 °C), salinity (38.966 ± 0.003‰), tritium (14.2 ± 0.3 T.U.) and oxygen (96.8 ± 0.4% sat.) values indicate that water convection reached a depth of about 200 m. The surface and deeper tritium concentrations are higher than those measured in the Levantine Basin (10–11 T.U.; this study) and in the western Mediterranean (8–10 T.U., Cortecci, Molcard and Noto, 1974a, b). A similar picture was found by Östlund (1969) for samples collected in 1965, after the fusion bomb tests of 1961–1962, in the central Aegean basin and in the western Mediterranean, where the tritium concentrations were 32 ± 5 T.U. and 18 ± 4 T.U., respectively, down to 100 m depth.

3.3. *Ionian Sea*

The subsurface waters above the salinity maximum have higher tritium concentrations moving westward, with 14 T.U. in the eastern Ionian and 19 T.U. in the western. At stations 20 and 16, the L.I.W. core layer shows the same tritium and oxygen concentrations (on average 9.8 ± 0.3 T.U. and 86.5 ± 0.1% sat.). At station 13, the salinity profile for values higher than 38.72‰, and down to about 350 m depth is fairly flattened compared to the more eastern one, the highest salinities (on average 38.857 ± 0.02) being measured at 250 and 300 m depth. The tritium gradient from 12.1 to 9.8 T.U. suggests that the L.I.W. flowing through this station is formed by upper and lower layers that have undergone mixing with more tritiated overlying and less tritiated underlying waters, respectively. Even if we cannot be entirely certain that this L.I.W. flows through the Straits of Sicily, because its flow pattern is unknown, the same tritium distribution was observed in the L.I.W. at station 8 in the Sicilian channel (see Fig. 2).

The tritium and oxygen concentrations generally decrease with depth. However, a significant inversion was found at station 20 at 300 m depth (11.9 T.U. and 90.2% sat.). These higher values could be explained by an advection of water from the Sea of Crete: in fact, at station 25, to the north of Crete, water having practically the same tritium (on average 12.5 T.U.) and oxygen (on average 90.5% sat.) content was measured from 170 to 270 m depth.

3.4. *Sicilian Ridge*

At station 8, the water of Atlantic origin, with salinity of less than 37.50‰, is in the top 100 m layer. Its tritium and oxygen concentrations are very uniform, with 8.0 T.U. and 100% saturation, respectively, the tritium concentrations being close to that measured in surface waters in the south Tyrrhenian Sea (Cortecci, Molcard and Noto, 1974a, b). Below this surface layer there is a transition layer about 150 m thick where the Atlantic water and the L.I.W. mix. The tritium distribution in the transition layer suggests a tritium concentration of more than 12 T.U. for the upper layer of the Levantine water mass that undergoes mixing, the lower part of the L.I.W. having 9.3 T.U.

3.5. *Tritium distribution in the L.I.W. core*

The results indicate that the L.I.W. core, traced by the maximum of salinity, shows practically the same tritium concentration (about 10.5 ± 0.5 T.U.) from the formation area to the central Ionian (station 16).

The uniform distribution of tritium in the L.I.W. core up to the central Ionian could indicate that the processes of mixing laterally, and with waters above and below, were not important. The L.I.W. core retained its original tritium concentration as the tritium depletion by radioactive decay was negligible, because of a relatively high flow rate. Alternatively, it could reflect time variations of the tritium concentrations in freshly formed L.I.W. water, coupled with the tritium decrease by radioactive decay as the L.I.W. core moves westward.

The first hypothesis seems to be more probable on the basis of the following considerations. The rainwater tritium concentrations measured around the Levantine basin (Antalya–Turkey, Maritsai–Rhodes and Yraklion–Crete meteorological stations) showed fairly constant yearly average T.U. values (about 65 ± 15 T.U.) from 1968 to 1971 (I.A.E.A. Environmental Data, 1970, 1971, 1973 and 1975) and probably up to 1974 (this survey). Thus, the input of tritium in the L.I.W. source regions and its tritium concentrations were probably more or less constant from 1968 on. Accordingly, the time spent by the L.I.W. to reach the central Ionian is probably less than 1 year, in agreement with the uniform tritium distribution observed in the L.I.W. core.

3.6. *Oxygen–tritium–salinity correlations*

A general positive correlation exists between tritium and oxygen (Fig. 3), particularly good for waters below 150–200 m depth, with the exception of the samples from station 8 in the Straits of Sicily. Here the exchange of different waters between the eastern and western basins prevents such correlation. The same trend results from the tritium, oxygen and salinity diagrams.

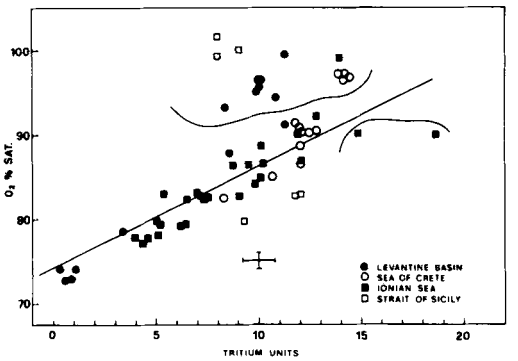

Fig. 3. Oxygen and tritium relationship. Samples down to 100 or 200 m, depending on the stations, and separated by curves, were not computed in the interpolation.

The deviations observed for surface and subsurface waters in the various basins can be explained by the different meteorological conditions and circulation patterns which determine particular tritium and oxygen concentrations.

The tritium–oxygen correlation for waters beneath 100–200 m depth may be explained as follows: when a seawater parcel leaves the surface and sinks, its tritium concentration decreases by mixing and radioactive decay and its molecular oxygen is consumed by biological and chemical processes. The greater depletion of oxygen in the water body very probably occurs above 100–200 m depth, just beneath the thermocline where easily oxidizable materials are decomposed and respiration processes prevail. Below this depth the oxygen utilization becomes very low and the oxygen concentration decreases very slowly with time. Thus deep waters with tritium concentrations around zero show fairly uniform and relatively high oxygen contents corresponding to about 73% sat.

4. Acknowledgements

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ПРОФИЛИ ТРИТИЯ И КИСЛОРОДА В ВОДАХ ВОСТОЧНОГО СРЕДИЗЕМНОМОРЬЯ

Приведённые здесь профили концентраций трития и кислорода были составлены в феврале и марте 1974 года и относятся к Сицилийскому проливу, Ионическому морю, Критскому морю и Левантинскому бассейну. В контрольных пунктах на юго-востоке от Родоса и на севере от Крита образцы самой солёной воды имеют и наиболее высокое содержание трития, соответственно 10,5 T.U. (единиц трития) и 14 T.U. В образцах же, взятых в Ионическом море и в Сицилийском проливе, максимальное содержание трития опережает максимум солёности со значениями от 12 до 19 T.U.

В образцах, взятых из средних слоёв воды в Левантинском море, обнаружена такая же концентрация трития (примерно 10 T.U.), что и в водах центральной части Ионического моря, что указывает на быстрое смещение вод в направлении запада.