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USE OF TRITIUM AND HELIUM-3 FOR THE STUDY OF OCEANOGRAPHIC PROCESSES. AN EXAMPLE : THE NORTHEASTERN ATLANTIC OCEAN

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ABSTRACT

These results relate to the TOPOGULF cruise during summer 1983. The sampled area is located near the Azores Islands on both sides of the Mid-Atlantic ridge. The tritium content of the surface waters reveals a strong front along the Azores current. At depth, the spatial distribution of tritium is studied along isopycnals. In the thermocline, it is essentially the anticyclonic gyre which is responsible for the northeast - southwest gradient in tritium concentration. Some information about the "age" of the water masses is given by the use of both tritium and Helium-3. In this way some areas where ventilation processes are active are identified. At middepth, a strong contrast exists between the young waters originating from the Labrador Sea and the more stagnant waters in the South East of the sampled area.

INTRODUCTION

In the form of HTO molecules tritium is an ideal tracer for the water masses circulation studies.

Large amounts of tritium entered the ocean from the atmosphere after the nuclear bomb testing starting in 1954. The larger inputs occured between 1963 and 1965. The time distribution of tritium concentration in surface water is relatively well documented (DREISIGACKER and ROETHER, 1978).

The transient nature of tritium and its half life (12.43 years) has already provided information about circulation processes in the North Eastern Atlantic ocean (SARMIENTO et al., 1982).

For the study of water mass transport and ventilation processes the simultaneous use of tritium and its radioactive daughter ^{3}He is specially adequate to deduce interior ocean travel times (JENKINS, 1980).

These two tracers have complementary boundary conditions at the ocean-atmosphere interface : this interface acts as a sink for the atmospheric tritium into the ocean and as a source for the oceanic gaseous helium-3 into the atmosphere. The "age" of a water mass, i.e the time elapsed since the water parcel has been isolated from the atmosphere can be determined from its helium-3 and tritium contents (JEAN-BAPTISTE et al, this issue).

The data are reported in δ^3He % for the ^3He excess (i.e. the anomaly of the isotopic ratio $^3He/^4He$ of the sample relative to the isotopic ratio of the atmosphere, expressed as a percentage) and in TU units for tritium (1 TU unit represents 1 tritium atom for 10^{18} hydrogen atoms). The age of each sample is calculated from $\tau = \lambda^{-1} \ln \left(1 + \frac{[^3HE]}{[^3H]}\right)$ where λ is the tritium decay constant equal to 0.0557 y^{-1} and $[^3He]$ and $[^3H]$ are the respective helium 3 and tritium contents of the sample (expressed in numbers of atoms).

FIELD WORK AND BACKGROUND

Figure 1 shows the stations sampled during the TOPOGULF cruise (July-August 1983). These are located in the area 24°N-40°N, 23°W-50°W near the Azores Islands along the Eastern and Western flanks of the Mid-Atlantic Ridge and perpendicular to it. The hydrological and nutrient data are given in the Data Report by the TOPOGULF Group (1986).

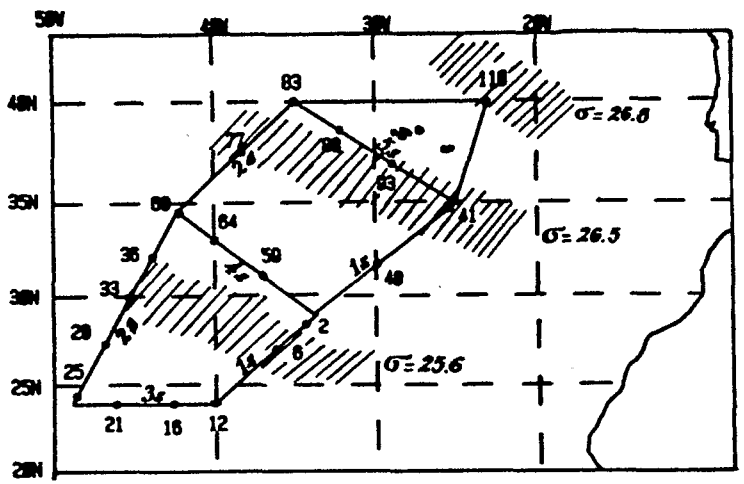


Figure 1 : Map of the TOPOGULF cruise (tracks 1s, 2s, 3s, 4s and 5s). The shaded are the approximate locations of the 25.6, 26.5 and 26.8 isopycnal levels.

Previous works relative to chemical or transient tracers distributions in the thermoclinal and middepth North Atlantic waters (JENKINS, 1980 ; SARMIENTO et al., 1982 ; KAWASE and SARMIENTO, 1985, 1986, THIELE et al., 1986) have shown that the tracers transport into subtropical anticyclonic gyre was essentially isopycnal.

We successively discuss the helium-3 versus density distributions along the five principal tracks of the cruise and their corresponding tritium and ^3H-^3He "age" distributions. In addition, salinity and oxygen data are used to identify some water masses along some specific isopycnal levels.

RESULTS AND DISCUSSION

Shaded areas in figure 1 correspond to the water outcropping location of the respective sigma-theta levels 25.6, 26.5 and 26.8 determined from historical wintertime temperature data from SARMIENTO et al., 1982.

In Figure 2 are given the respective helium-3 versus sigma-theta distributions of the tracks 1s and 2s on the Eastern and Western flanks of the MAR and on the tracks 3s, 4s and 5s perpendicular to the MAR (see Figure 1). On each Figure are drawn the respective sigma-theta levels 25.6, 26.5, 26.8. 27.1 and 27.4. The four first levels outcrop in winter in the subtropical anticyclonic gyre, the last one outcrops in the subarctic gyre. These distributions are the results of three processes : convection processes which are responsible for the helium-3 evasion, tritium penetration which generates helium-3, and the age of the water masses which increases the helium-3 regrowth by radioactive decay.

For the surface as well as for the first isopycnal level 25.6 the mean δ^3He values obtained for the samples over the whole TOPOGULF area are respectively - 1.21 % and - 1.44 %. These values agree with the previously observed excess ^3He in the ocean surface layer (FUCHS et al., 1987) as compared to the solubility equilibrium value of - 1.7 % from BENSON and KRAUSE, 1980.

Figure 3 gives the respective tritium and ^3He-^3H age versus sigma-theta distributions for the Western and Eastern tracks 2s and 1s.

We observe a very homogeneous tritium surface content in the area located South of 34°N (4.5 ± 0.15 TU81N). The tritium versus salinity diagram on Figure 4 shows that this homogeneity does not extend to salinities smaller than 36.4 ‰which characterize the Azores front. North of the front we observe the greatest tritium concentration. This tritium increase with latitude is essentially the result of the latitudinal distribution of the tritium input function.

We report, for some isopycnal levels, informations relative to ventilation, transport and mixind using tritium and helium-3 data :

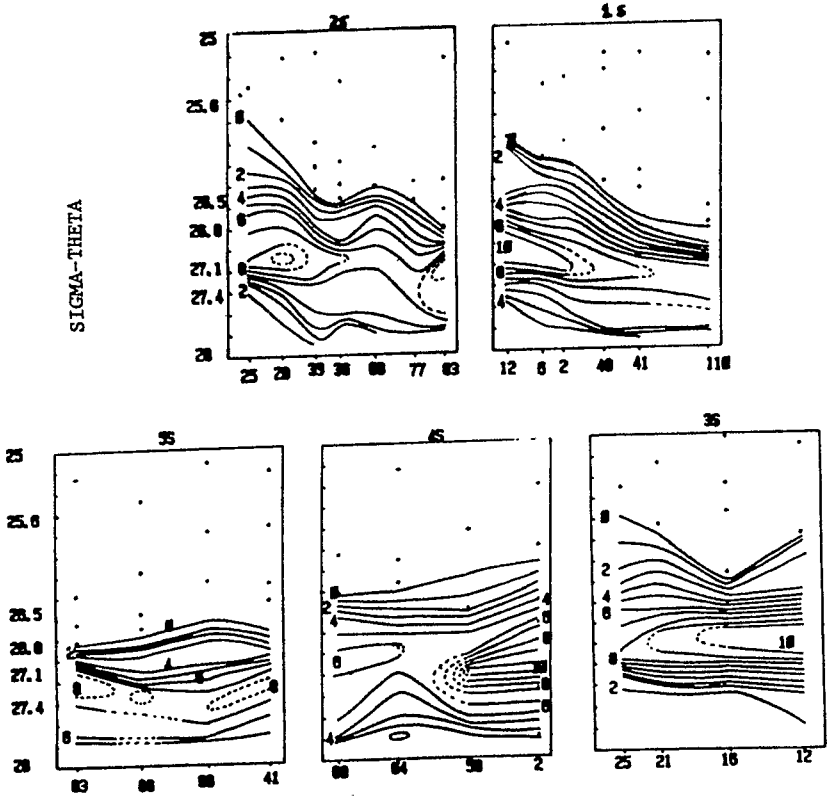


Figure 2 : δ^3He (%), valves plotted on diagrams of sigma-theta versus station number for the 1s, 2s, 3s 4s and 5s tracks in figure 1.

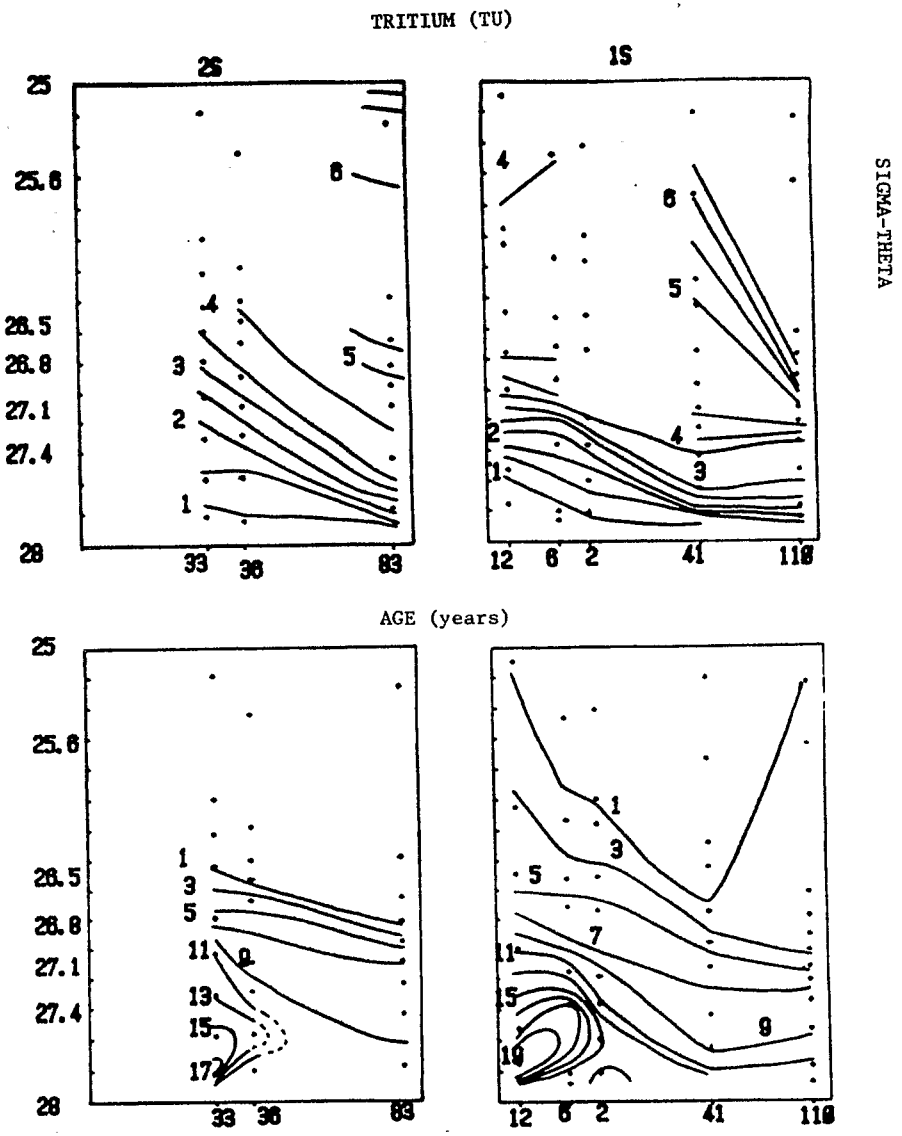


Figure 3 : Tritium concentrations and water mass "ages" plotted on diagrams of sigma-theta versus station number for the Western and Eastern tracks 2s and 1s.

On the 26.5 isopycnal level, we observe tritium concentrations in the South (Stations 12, 6, 2) higher than the corresponding tritium content of the surface waters. On figure 1, we can observe that the wintertime outcrop of this isopycnal takes place North of the Azores front : the tritium enrichment of the Southern stations on the 26.5 sigma-theta level is the result of the transport of tritium enriched waters from an area located to the north of 35°N by the anticyclonic gyre. On the same isopycnal, we observe for the station 33 and 36 relatively low tritium concentrations (Figure 3) correlated with negative δ^3He values (Figure 2) suggesting a remainder of surface convection. On the 26.5 isopycnal level these stations are more imprinted by the 18°C Mode Water than by the anticyclonic gyre. In the North we observe everywhere negative δ^3He values as the result of recent convection.

On the 26.8 isopycnal level in the North (Figure 5) we observe a subsurface maximum for the three stations 83, 93 and 110. This level is the first one for which the wintertime outcrop is located North of the 4°N latitude : this maximum corresponds to the enriched tritium surface waters of Northern origin.

The wintertime outcrop of the 27.4 isopycnal occurs North of the anticyclonic gyre. This can explain the second maxima observed for stations 83 and 93 (Figure 5). The tritium versus salinity and versus oxygen diagrams on Figure 6 indicates the tritium enriched 83, 88 and 93 are originating from the Labrador Sea water characterized by a high oxygen content. On the opposite, the Mediterranean input is well noticeable for stations 110 and 41 with a high salinity responsible for a tritium decrease. On this level, we observe the greatest North-South assymetry due to the imprint of the Antarctic Intermediate Water characterized by a low salinity and a low tritium content (see stations 6, 12 and 16 on Figure 6).

At intermediate depths (27.1 isopycnal level), the tritium data permit to quantify the transit time of the waters. The Northeast-Southwest assymetry of the tritium distributions (Figure 3) suggests that the gyre scale circulation has dominated the redistribution process during the twenty years duration of the transient. We can evaluate from the tritium content of respectively 4.6 and 3 TU for the stations 110 and 12 (Figure 3) a transit time of around 7.5 years assuming an isopycnal advection process. This leads to an advection rate of 1cm/s.

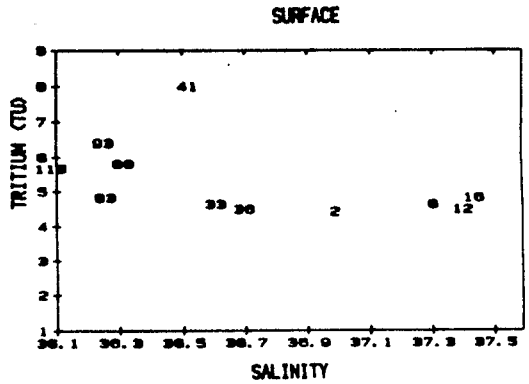


Figure 4 : Tritium versus salinity diagram for the surface waters.

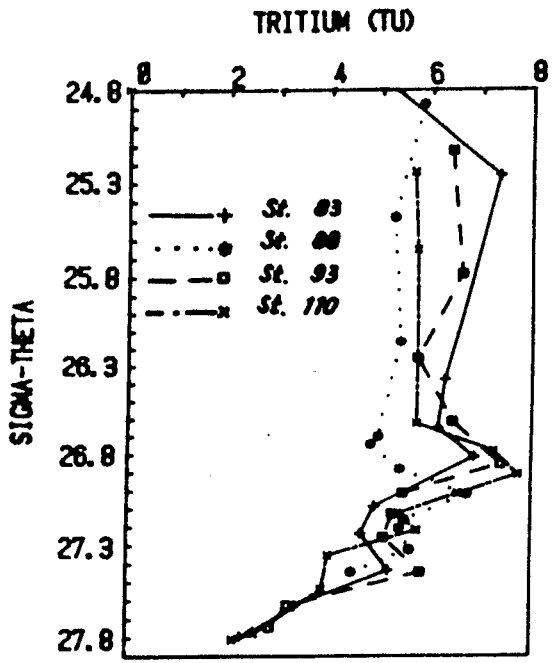
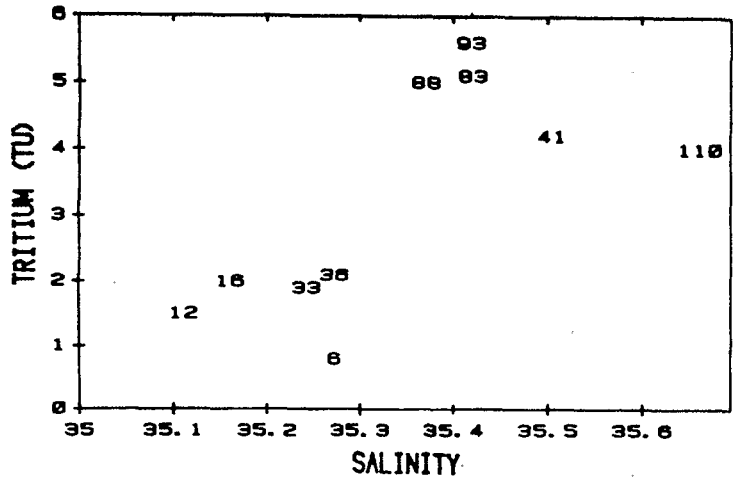


Figure 5 : Tritium versus sigma-theta distributions of the Northern stations.



SIGMA 27.4

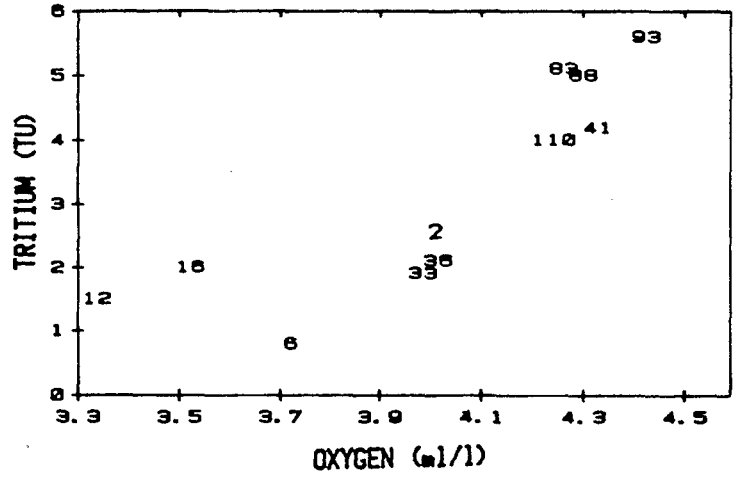


Figure 6 : Tritium versus salinity and tritium versus oxygen diagrams for the 27.4 isopycnal level. Numbers plotted are station numbers

SIGMA 27.8

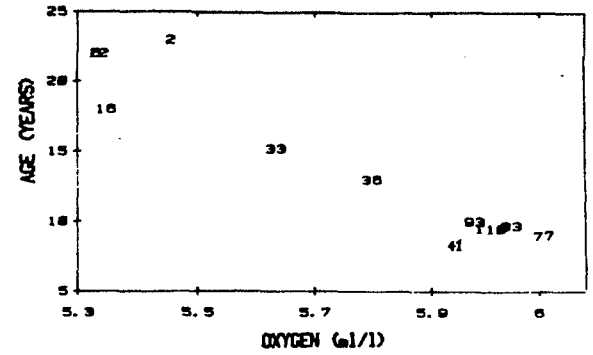


Figure 7 : Age versus oxygen diagram for the 27.8 isopycnal level. The young waters (age ≈ 10 years) of oxygen enriched content originate from the Labrador Sea. The old waters (stations 2, 6, 12, 16) of low oxygen are "stagnant" waters.

CONCLUSION

Finally, the simultaneous use of tritium and helium data gives important information relative to the thermocline ventilation.

The "age" of each sample, determined by its tritium and helium-3 contents, is an useful tool to characterize the ventilation degree of the waters.

For the waters located just above the 27.8 isopycnal level we identify (Figure 3) two kinds of water masses : young water masses about 10 years old in the North of the Eastern and Western sections, old water masses at least 20 years old in the South of the Eastern section.

The young waters are of Labrador origin while the old ones correspond to stagnant waters corresponding to the previously named "shaded area" water (Figure 7). Our evaluation of the age of the LSW in the Northern area (of around 10 years) agrees with the volumetric calculation of TALLEY and Mc CARTNEY (1982) giving a ventilation time for the LSW of around 9 years.

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MESURE DU COUPLE TRITIUM/HELIUM OCEANIQUE PAR SPECTROMETRIE DE MASSE

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RESUME

Nous décrivons la technique expérimentale de mesure des isotopes de l'hélium (^{3}He et ^{4}He) dans l'eau de mer par spectrométrie de masse ainsi que la méthode de dosage du tritium océanique par analyse de l'hélium-3 de décroissance. Les protocoles analytiques sont reportés ainsi que la précision de chacune des méthodes. Enfin, l'intérêt de l'acquisition du couple de données hélium-3/tritium est explicité au-travers de la détermination de "l'âge" d'une masse d'eau.

ABSTRACT

We describe the experimental procedure of the mass spectrometric measurements of the dissolved helium isotopes (^{3}He and ^{4}He) in seawater and the analytical method of the oceanic tritium determination by the β-regrowth technique. The experimental procedures and the analytical accuracies of each method are reported. Finally, the interest of the helium-3/tritium pair is emphazised through the determination of a water mass "age".

INTRODUCTION

Le tritium et son descendant, l'hélium-3, connaissent une utilisation croissante en océanographie. De par leur caractère chimiquement inerte vis-à-vis du milieu océanique et de par l'aspect transitoire de l'injection du tritium dans l'océan, le couple ^{3}He-^{3}H constitue une source unique d'information par rapport aux traceurs à l'état stationnaire.

La spectrométrie de masse permet d'accéder à des mesures de tritium et d'hélium-3 suffisamment précises pour pouvoir évaluer "l'âge" d'une masse d'eau c'est-à-dire le temps écoulé depuis qu'elle a quitté l'interface océan-atmosphère.

RADIONUCLIDES: A TOOL FOR OCEANOGRAPHY

Edited by
J.C. Guary, P. Guegueniat and R.J. Pentreath

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