Water mass analysis of the north-west Iberian ocean margin

Hendrik M. van Aken

Netherlands Institute for Sea Research (NIOZ)
P.O. Box 59, Texel, The Netherlands

ABSTRACT

From a data set of historical hydrographic data the large-scale hydrography of the permanent thermocline in the north-eastern Atlantic Ocean has been established. Also hydrographic data from OMEX II-II cruises have become available for analysis. Inter-annual and seasonal changes of the thermohaline structure of the Eastern North Atlantic Central Water have been described. The non-conservative tracers like Apparent Oxygen Utilization and dissolved nutrients in isopycnal surfaces from the thermocline mainly show meridional gradients. This agrees with uniform ageing of subducted water in the southward flow of the subtropical gyre. Possibly enhanced productivity due to seasonal upwelling near the Ocean Margin and subsequent mineralization of sinking organic particles do not show any clear signature in the permanent thermocline in the OMEX II-II area. But from OMEX data from 1997, and 1998, obtained at shallower levels in and just below the seasonal thermocline such a signal can be observed in summer. It has the form of a sub-surface maximum of the Apparent Oxygen Utilization between 40 and 80 dbar over the continental shelf and upper slope.

HISTORICAL DATA (**Task II.1.1**)

In order to be able to interpret the observations of the water mass near to north-west Iberian ocean margin in a larger scale context, a historical data set has been assembled for the area between 31 and 53°N, and east of 21°W. This data set mainly covers the period from 1987 till present. The data originate from several British, German, and Dutch WOCE Hydrographic Program cruises (WHP areas AR7E, AR12 and AR16), pre-WOCE cruises available from the Scripps Institution of Oceanography (web-site L. Talley), cruises from the Galicia and MORENA projects, and data from the ICES oceanographic data base in Copenhagen. Because of the emphasis of the OMEX programme, the assembled historical data focus on the European ocean margin.

The historical data sets consist of two parts, CTD (O_2) data and hydro-chemistry data. The latter contain records of pressure, temperature salinity and dissolved oxygen, phosphate, nitrate, and silica data. When assembling the data care was taken that all concentrations were expressed in similar units (μmol kg^{-1}). Quality control was carried out in order to obtain an internally consistent data set. Evidently outlying values were removed. In the first year of the OMEX II-II programme these data have been used to establish the large-scale water mass structure at deep and intermediate levels. In the second year the water mass analysis was shifted to the study of the Central Water in the permanent thermocline. Special attention was given to the inter-annual variability in the OMEX II-II area.

OMEX DATA (**Task II.2.1**)

The hydrographic data collected on board RV *Pelagia* have been processed and controlled at NIOZ. With BODC, which collect, process and archive all hydrographic data from the different OMEX cruises, quality control has been carried out also for other OMEX II-II cruises. Some problems have arisen regarding the calibration of salinity and nutrient analyses. Steps have been taken to come to well calibrated data. The data flow of hydro-chemical data (oxygen and nutrients) is still lagging behind the intended submission rate. Comparison with historical data (*e.g.*, from Galicia and MORENA cruises) indicates that the OMEX II-II data are within the expected ranges and hydrographic structure. The historical and OMEX II-II data reveal an inter-annual variability of the Θ-S properties of the Eastern North Atlantic Central Water (ENACW) in the permanent thermocline (Figure 1). After a salinity minimum in 1995 the salinity of the Central Water was restored in the summer of 1997 to its 1993 characteristics. In 1998 the salinity of the warmest ENACW showed a slight (~0.05) decrease again. In the 1997 to 1999 period the main inter-annual variability of the

Central Water is observed at temperatures Θ > 12.5°C. This temperature range also shows most of the seasonal variability with relatively low salinities in winter and spring, and high salinities in summer. That feature appears to be connected with the seasonally varying slope current with a narrow pole-ward flow in winter and a equator-ward flow with westward extending filaments in summer. The salinity minimum of the ENACW in 1995 apparently coincides with a similar 1995 salinity minimum in the northern Bay of Biscay and along the continental slope in the Rockall Channel. The cause of this large-scale hydrographic feature is not known yet.

CONSERVED NUTRIENT TRACERS (**Task II.4.2**)

As a measure of the oxygen content, independent of the temperature dependent solubility, the apparent oxygen utilization (AOU) is used, defined by:

$$AOU = O_{2sat} - O_2 \qquad (1)$$

where O_2 is the dissolved oxygen concentration, and O_{2sat} is the saturation concentration in equilibrium with the atmosphere (Broecker and Peng, 1982). Whereas salinity and potential temperature behave conservative, the concentration of *e.g.*, dissolved oxygen is not conservative and will decrease due to ageing of sub-surface water masses while AOU and nutrient concentrations will increase. We can consider such changes of non-conservative parameters as a qualitative measure for ageing, only indicating the characteristic direction of the flow of a water mass from "young" (low AOU) to "old" (high AOU).

The ratio of the bio-geochemical tracers involved in the mineralization of organic matter can be quantified by stochiometric ratios $-\Delta O_2:\Delta NO_3:\Delta PO_4$ (Redfield et al., 1963). Pérez et al. (1993) obtained, from a linear regression of oxygen and nutrient anomalies in the waters off the Iberian Peninsula, the ratios $-\Delta O_2:\Delta NO_3:\Delta PO_4$ = 163:16.3:1 without a clear depth dependence, not significantly different from the ratios for the North Atlantic Ocean obtained by other authors. We will use the stochiometric ratios given by Pérez et al. (1993) to determine the pre-formed phosphate PO_4^o and pre-formed nitrate NO_3^o, defined as:

$$PO_4^o = PO_4 - AOU/163 \qquad (2)$$
$$NO_3^o = NO_3 - AOU/10 \qquad (3)$$

Because the pre-formed parameters are not effected by ageing, generally the spreading of the pre-formed concentrations is less then the spreading of the in-situ nutrient concentrations (Figure 2). The pre-formed nutrient data have been used effectively as a quasi-conservative tracer in the study of the large-scale water mass structure of the north-eastern North Atlantic Ocean. The nearly linear relation between the potential temperature and the pre-formed phosphate concentration reflects the large-scale correlation of sea surface temperature and sea surface nutrient concentrations in winter (van Aken and Becker, 1996), before the water subducts into the permanent thermocline.

WATER MASS ANALYSIS (**Tasks II.1.5**, **II.2.1**, **II.2.2**, and **IV.1**)

The large-scale structure of bio-geochemical parameters of the permanent thermocline in the north-eastern Atlantic Ocean (31 to 53°N, east of 20°W) were studied by the use of historic hydrographic data. In the eastern part of the sub-tropical gyre in the North Atlantic Ocean the water mass in the permanent thermocline is formed by subduction of near surface water formed by winter convection. After subduction this ENACW is assumed to flow towards the equator. Having list direct contact with the sea surface and the photic zone the subducted ENACW ages by mineralization of organic water. This is confirmed by the large-scale southward increase of AOU in isopycnals from the permanent thermocline (Figure 3). In isopycnal surfaces AOU and latitude appear to be well correlated. The latitudes where the AOU values approximate zero are assumed to be formation latitudes of ENACW. Our results (Figure 3) suggest that most of the ENACW in the OMEX II-II are off Galicia is subducted at latitudes south of the Porcupine Sea Bight (~53°N). The ageing, derived from the southward AOU increase, is also shown in the southward increasing trends of dissolved nutrients whereas the pre-formed nutrients do not show a large scale meridional trend in isopycnal surfaces (Figure 4). In the permanent thermocline zonal gradients of AOU and dissolved nutrients appear to be very small compared to the meridional trend, even near the ocean margin (van Aken, 1999).

At shallower levels in the seasonal thermocline definite zonal gradients have been observed in the OMEX II-II research area. The profiles of AOU, measured in the summers of 1997 and 1998, show at shallow pressure levels ($p < 75$ dbar) many samples with negative AOU values (Figure 5a), related to primary production in spring and summer. In the same pressure interval however also positive AOU values are observed, culminating in sub-surface AOU maxima in the 40 to 80 dbar pressure interval. In winter the AOU values in the convectively mixed upper 100 dbar are approximately in the range 0 to 10 μmol kg^{-1}, increasing to higher values in the permanent thermocline (Figure 5b). The highest AOU values in the sub-surface AOU maximum are found over the continental shelf and upper slope, whereas as similar densities over deeper water the AOU values become near zero or even positive (Figure 6). Probably the sub-surface AOU maximum is caused by mineralization of organic matter falling from the highly productive surface layer of the near shore ocean, while further off-shore primary production reaches deeper levels. In the near shore ocean convective mixing in winter probably smoothes the vertical structure of AOU and nutrients, generated in the preceding growing season. This bring the nutrients (and probably also dissolved inorganic carbon) back to the surface layers. It can be expected that the string mineralization in the sub-surface AOU maximum in summer may considerably reduce the amount of organic matter that reaches the sediment.

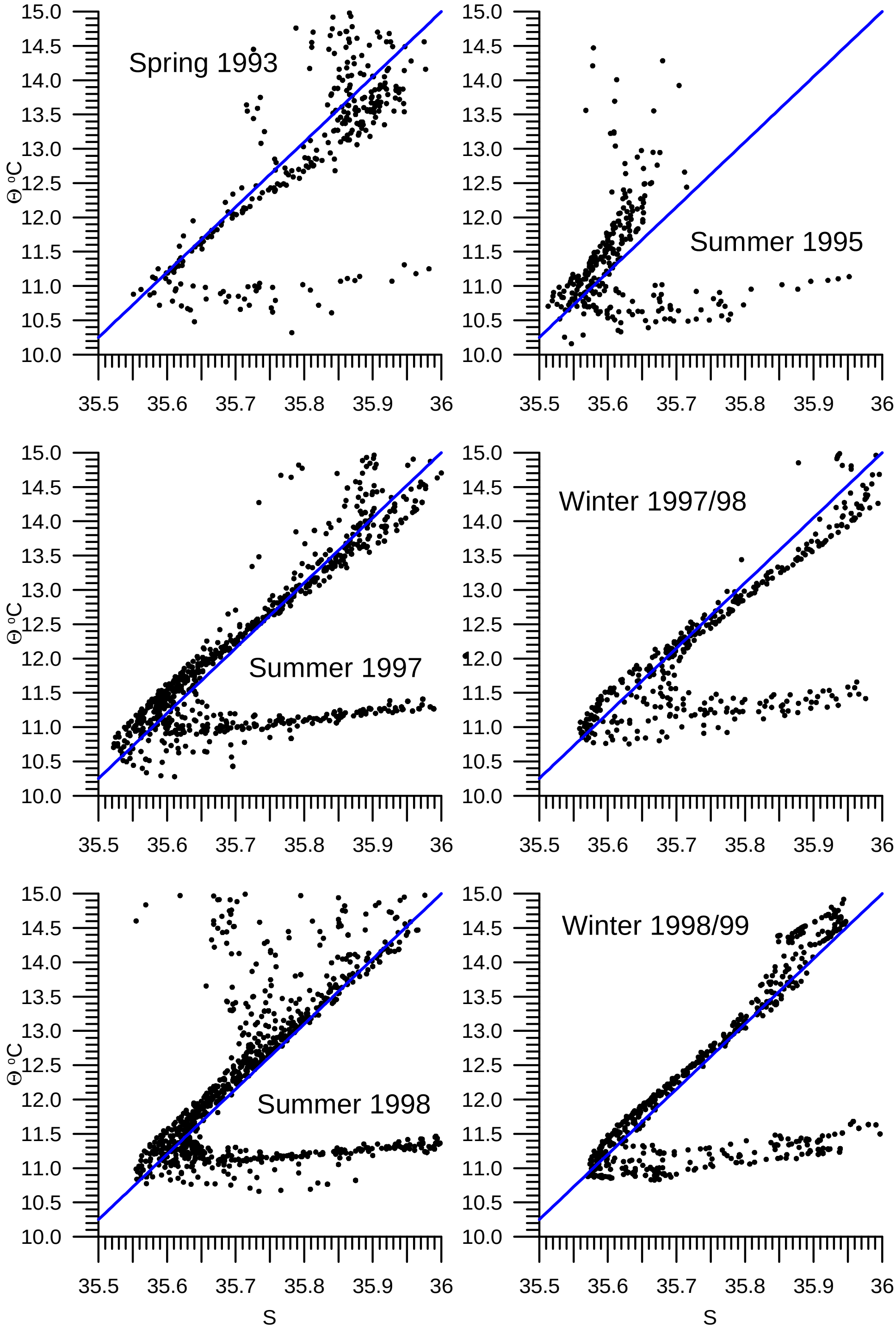


Figure 1. Potential Temperature-Salinity diagram of the thermocline water mass in the OMEX II-II research area for different years and seasons. The straight reference line is characteristic for ENACW in the summer of 1998.

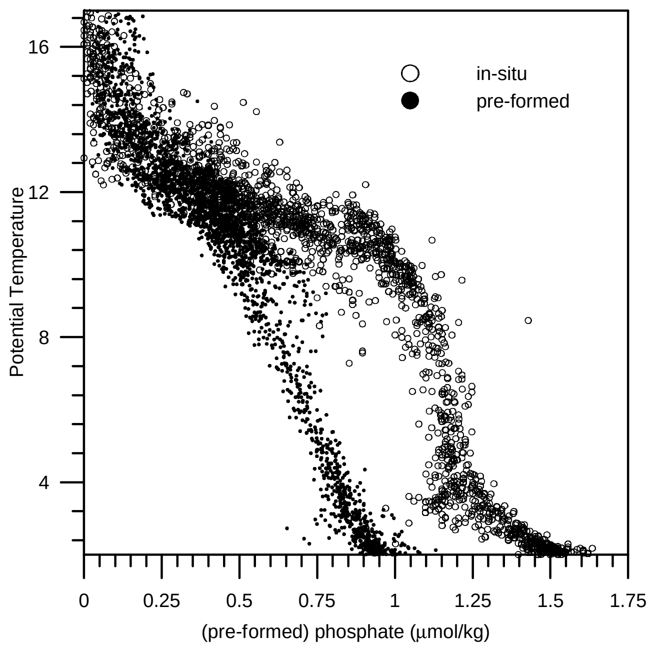


Figure 2. Plot of in-situ phosphate concentrations (dots) and pre-formed phosphate concentrations (circles) *versus* potential temperature. This plot is based on water samples from the database of historical data from the north-eastern Atlantic Ocean.

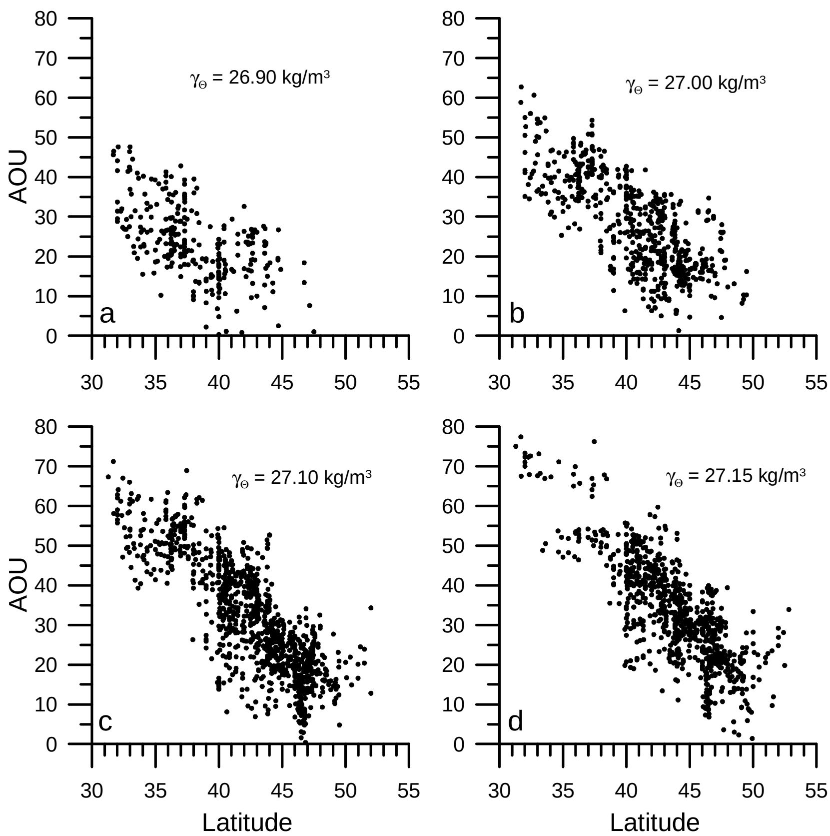


Figure 3. Plots of AOU versus latitude for four different isopycnals from the permanent thermocline. The data for these plots were obtained from the area 31 to 53°N, east of 20°W. The γ_Θ = 27.15 kg m^{-3} surface is found in the OMEX II-II area just above the sub-surface salinity minimum between the Central Water and the Mediterranean Water.

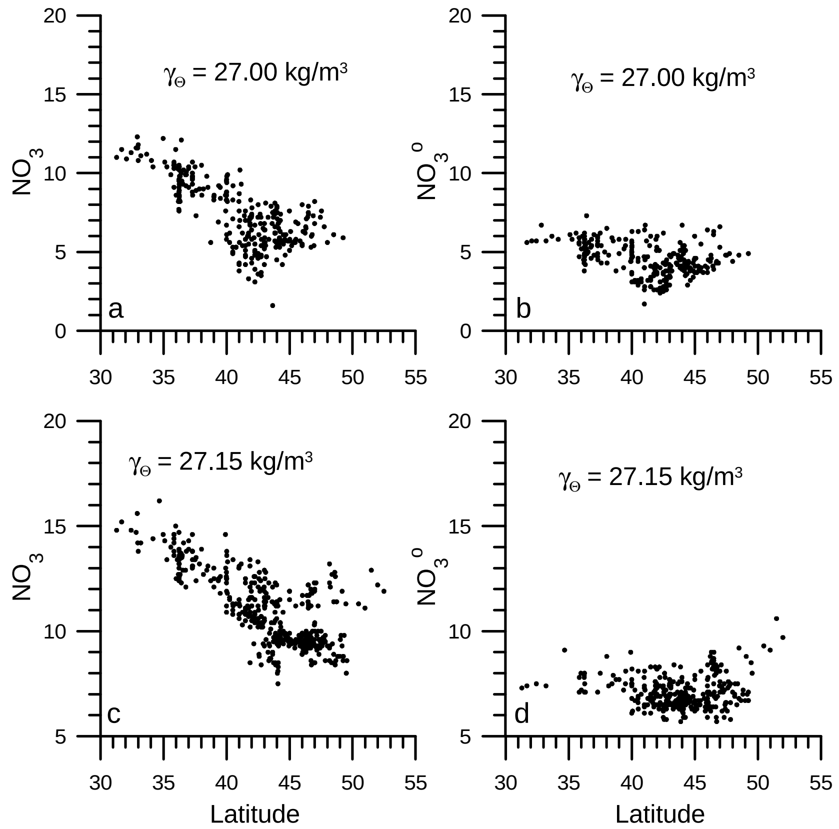
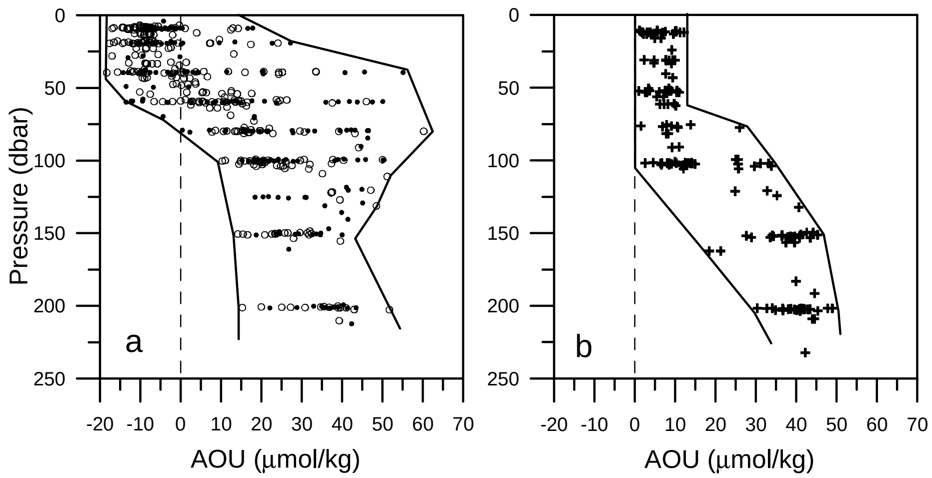


Figure 4. Plots of in-situ and pre-formed nitrate concentrations versus latitude in the γ_Θ = 27.00 and 27.15 kg m^{-3} isopycnals from the permanent thermocline in the Northeast Atlantic. The data for these plots were obtained from the area 31 to 53°N, east of 20°W.

Figure 5. Profiles of AOU in the summer (a) of 1997 (dots) and 1998 (circles) in the winter (b) of 1999.



The data were obtained from the cruises of OMEX cruises of RV *Belgica*, RV *Charles Darwin* and RV *Meteor*. The full lines indicate the approximate envelopes of the data points per season.

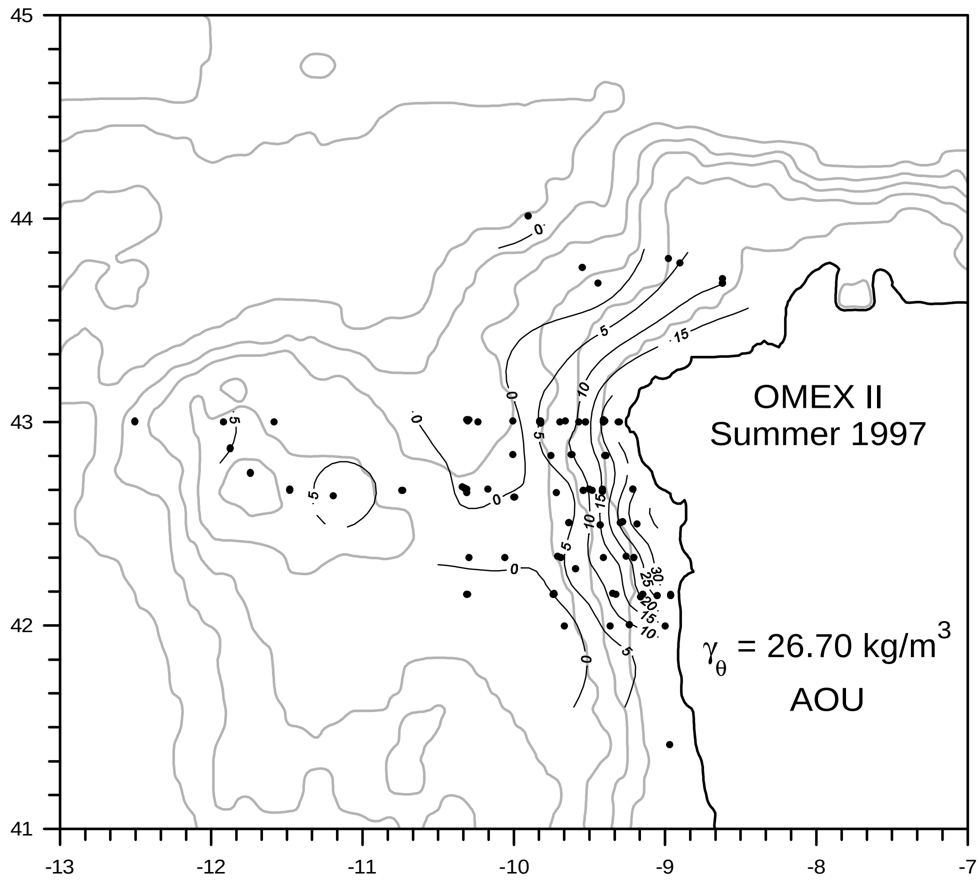


Figure 6. The lateral distribution of AOU (μmol kg^{-1}) in the γ_Θ = 26.70 kg m^{-3} isopycnal surface.
This surface is found at a characteristic pressure of about 65 dbar, in the lower parts
of the seasonal thermocline and more or less coincides with the sub-surface AOU maxima.
The isobaths (grey lines) show the 200, 1000, 2000, 3000, 4000 and 5000 depth levels.

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