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Water mass analysis of the 2013 US GEOTRACES eastern Pacific zonal transect (GP16)

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ABSTRACT

The 2013 US GEOTRACES Eastern Pacific Zonal Transect (GP16) extended from the Peruvian coast to Tahiti, along a line that fell between 10 and 15°S. This transect sampled the Peruvian oxygen deficient zone (ODZ) and the hydrothermal plume extending from the East Pacific Rise (EPR) for a variety of trace elements and isotopes (TEIs). Here we report nutrient and hydrographic measurements collected on this cruise, as well as results from an Optimum Multiparameter Analysis (OMPA) to quantify the fractional contributions of endmember water masses in each sample. The primary goals of this study were to better understand the distribution of water masses in the eastern tropical Pacific, and to help interpret TEI measurements collected on this cruise, as well as related studies carried out in the region. In the thermocline, Equatorial Subsurface Water (ESSW) dominated the low oxygen waters of the eastern tropical South Pacific, blending into Eastern South Pacific Intermediate Water (ESPIW) and South Pacific Central Water (SPCW) further west. Below the thermocline, distributions of Antarctic Intermediate Water (AAIW) and Equatorial Pacific Intermediate Water (EqPIW) were relatively homogenous along the section between 800 and 1200 m depth. Deeper in the water column, distinct water mass signatures were found on opposite sides of the EPR: southward flowing Pacific Deep Water (PDW) dominated the basin east of the EPR, while the northward flowing Antarctic Bottom Water (AABW) and Lower Circumpolar Deep Water (LCDW) had the strongest contributions on the western side of the EPR. These findings support previous studies that indicate the Peruvian ODZ is largely contained within ESSW and that the EPR plays an important role in steering water mass distributions in the deep waters of the tropical Pacific. Overall, these results agree well with previous water mass analyses in this region and are consistent with the general circulation patterns in the eastern tropical Pacific.

1. Introduction

The US GEOTRACES Eastern Pacific Zonal Transect (GEOTRACES cruise GP16) was conducted on board the R/V Thomas G. Thompson between October and December 2013. The cruise began in the nutrient-rich coastal upwelling region adjacent to Peru, which is home to one of the world's largest permanent oxygen deficient zones (ODZs), and it ended on the edge of the oligotrophic south Pacific subtropical gyre at a station located ~5° north of Tahiti (Fig. 1). The cruise track allowed for sampling of waters associated with a large hydrothermal plume dispersing west from the East Pacific Rise (EPR), which was enriched in a number of trace elements, including dissolved iron (Fe), manganese (Mn), and aluminum (Al) (Resing et al., 2015).

The permanently low oxygen concentrations ($[O_2]$) in the Peruvian ODZ are thought to be controlled by intense O_2 consumption driven by upwelling and high surface productivity (Helly and Levin, 2004; Paulmier et al., 2006), and slow physical circulation that fails to re-supply O_2 in the subsurface waters (Reid, 1965; Luyten et al., 1983; Karstensen et al., 2008; Czeschel et al., 2011). In addition to low or non-detectable $[O_2]$, two other distinguishing features of the Peruvian ODZ are: 1) the secondary nitrite (NO_2^-) maximum, where dissimilatory reduction of nitrate (NO_3^-) is thought to drive substantial

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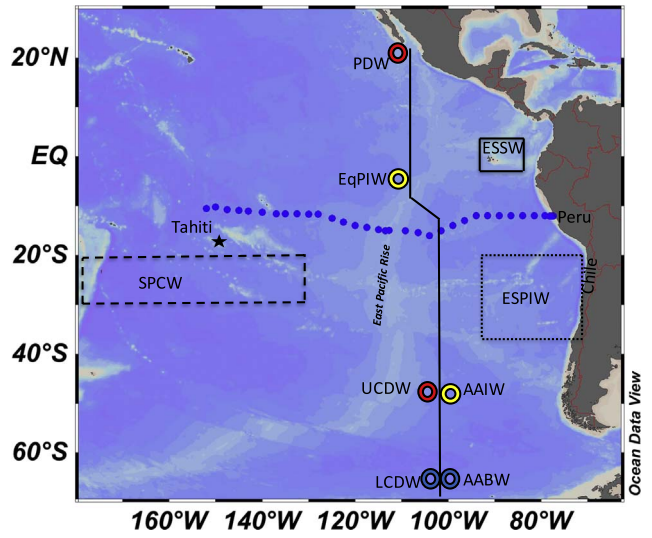

Fig. 1. The GEOTRACES GP16 cruise track (filled blue dots) and 2007 CLIVAR P18 cruise track (black line), which was used to define the properties of the water masses in the intermediate and deep OMPAs. The approximate location where each water mass was defined along the P18 section is shown by the open circles: yellow circles indicate water masses used only in the intermediate OMPA (EqPIW and AAIW), blue circles indicate water masses included only in the deep OMPA (LCDW and AABW), and the red circles indicate water masses included in both the intermediate and deep OMPAs (UCDW and PDW). The three boxes show the geographic range of water masses defined for the thermocline OMPA (ESSW, ESPIW, and SPCW) using the Global Ocean Data Analysis Project version 2 data product (GLODAP v2). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

accumulation of NO_2^- in low oxygen waters (Fig. 2A), and 2) low N* values ($N^* = [NO_3^-] + [NO_2^-] - 16 * [PO_4^{3-}] + 2.9\ \mu mol/kg$; Fig. 2B), which indicate conversion of fixed nitrogen (NO_3^-, NO_2^-, and ammonium (NH_4^+)) to dinitrogen gas (N_2) via microbial processes of denitrification and anammox. These processes involved in the production of N_2 in the Peruvian ODZ have previously been identified as important sinks of fixed nitrogen in the ocean (Anderson et al., 1982; Codispoti and Christensen, 1985; Thamdrup et al., 2006; Thamdrup et al., 2012) as well as a major source of nitrous oxide (N_2O) to the atmosphere (Paulmier et al., 2008; Arevalo-Martinez et al., 2015).

Many metals also exhibit distinct distributions in ODZs, particularly those that undergo oxidation-reduction reactions. For example, dissolved Mn is known to exhibit a subsurface maximum in ODZs. This maximum is believed to be driven by reductive dissolution of Mn oxides, although the redox cycle is complicated and the exact source of these Mn oxides is still under debate (Klinkhammer and Bender, 1980; Landing and Bruland, 1987; Lewis and Luther, 2000; Vedamati et al., 2015). Likewise, Fe behaves dynamically in ODZs. For example, maxima in Fe(II) have been reported to coincide with the secondary NO_2^- maximum (Moffet et al., 2007; Kondo and Moffett, 2015). This implies a potential link between Fe and nitrogen cycling in the ODZ, although the exact mechanisms still need to be explored. As the dissolved Fe and other reduced metals released from ODZs may contribute to productivity in overlying waters, it is important to understand the cycling mechanisms and how water mass mixing controls their distributions. Below the ODZ, Resing et al. (2015) reported a plume containing surprisingly high concentrations of dissolved Fe extending westward from the Peruvian slope. At present, we do not know the source of this deep Fe plume (which also exhibits a slight deficit of fixed nitrogen; Fig. 2B), or its trajectory. It will be helpful, therefore, to determine whether this plume is associated with a discrete water mass.

The other major oceanographic feature sampled on GP16 was a hydrothermal plume emanating from the southern EPR, known to be a 'super-fast' spreading center (DeMets et al., 1990). Hydrothermal activity is more abundant along this section of ridge crest than anywhere else on Earth (Beaulieu et al., 2013), leading to large fluxes of metals, such as Fe and Mn, that are leached from young ocean crust and released into the base of the oceanic water column (Von Damm, 1990; Elderfield and Schultz, 1996; German and Seyfried, 2014). It was previously thought that much of the dissolved Fe emitted from hydrothermal vents was rapidly lost as it became oxidized in seawater (German et al., 1991; Rudnicki and Elderfield, 1993; Feely et al., 1996), while dissolved Mn, which is slower to oxidize, could be carried as far as 2000 km from the vent site (Klinkhammer and Hudson, 1986). Recent work from GP16, however, has shown that both dissolved Fe and Mn emitted from the EPR are transported 4000 km or more from the vent site (Resing et al., 2015). It is clear that much more work remains to be done to understand metal cycling in and around the EPR and spreading centers elsewhere (German et al., 2016).

One of the major goals of the GEOTRACES program is to understand the sources, sinks, and internal cycling of trace elements and isotopes (TEIs) based on their distributions in the global ocean. In order to interpret source and sink functions from these distributions, it is informative to first understand the 'background' or 'preformed' properties within each water sample, based on individual water mass contributions to that sample. This information can help discern the extent to

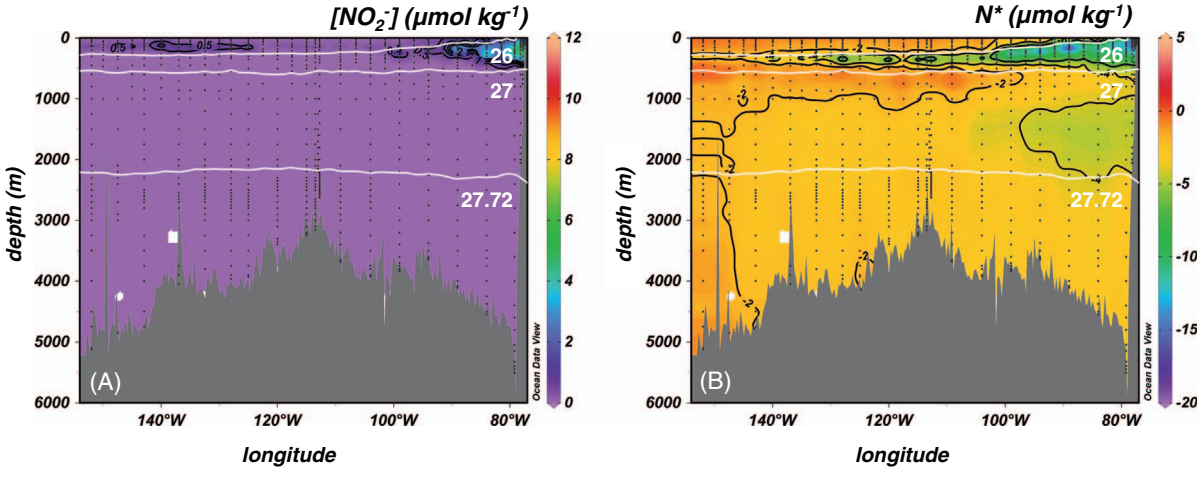

Fig. 2. Observed sections of $[NO_2^-]$ (A) and N* (B) on GP16. N* is calculated from ($[NO_2^-] + [NO_3^-] - 16 * [PO_4^{3-}] + 2.9\ \mu mol/kg$). The accumulation of NO_2^- in oxygenated waters just below the surface is known as the 'primary NO_2^- maximum', while the subsurface accumulation of NO_2^- in O_2 deficient waters is known as the 'secondary NO_2^- maximum'. Contours for each parameter are shown in black, while isopycnal surfaces defining the thermocline (σ_0 = 26.0–27.0 kg m^{-3}), intermediate (27.0 < $\sigma_0 \leq$ 27.72 kg m^{-3}), and deep ($\sigma_0 >$ 27.72 kg m^{-3}) layers are contoured in white for reference.

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