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Size-fractionated major particle composition and concentrations from the US GEOTRACES North Atlantic Zonal Transect

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ABSTRACT

The concentration and the major phase composition (particulate organic matter, CaCO₃, opal, lithogenic matter, and iron and manganese oxyhydroxides) of marine particles is thought to determine the scavenging removal of particle-reactive TEIs. Particles are also the vector for transferring carbon from the atmosphere to the deep ocean via the biological carbon pump, and their composition may determine the efficiency and strength of this transfer. Here, we present the first full ocean depth section of size-fractionated (1–51 μm, > 51 μm) suspended particulate matter (SPM) concentration and major phase composition from the US GEOTRACES North Atlantic Zonal Transect between Woods Hole, MA and Lisbon, Portugal conducted in 2010 and 2011. Several major particle features are notable in the section: intense benthic nepheloid layers were observed in the western North American margin with concentrations of SPM of up to 1648 μg/L, two to three orders of magnitude higher than surrounding waters, that were dominated by lithogenic material. A more moderate benthic nepheloid layer was also observed in the eastern Mauritanian margin (44 μg/L) that had a lower lithogenic content and, notably, significant concentrations of iron and manganese oxyhydroxides (2.5% each). An intermediate nepheloid layer reaching 102 μg/L, an order of magnitude above surrounding waters, was observed associated with the Mediterranean Outflow. Finally, there was a factor of two enhancement in SPM at the TAG hydrothermal plume due almost entirely to the addition of iron oxyhydroxides from the hydrothermal vent. We observe correlations between POC and CaCO₃ in large (> 51 μm) particles in the upper 2000 m, but not deeper than 2000 m, and no correlations between POC and CaCO₃ at any depth in small (< 51 μm) particles. There were also no correlations between POC and lithogenic material in large particles. Overall, there were very large uncertainties associated with all regression coefficients for mineral ballast (“carrying coefficients”), suggesting that mineral ballast was not a strong predictor for POC in this section.

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1. Introduction

Particles in the ocean, or suspended particulate matter (SPM), play a vital role in the cycling of trace elements and isotopes (TEIs), and are thus a key parameter in the international GEOTRACES program (GEOTRACES, 2006). Particles can be delivered by sources external to the ocean and bring TEIs to the water column. Particles can also be generated within the ocean through biological carbon fixation and biogenic and abiotic mineral precipitation, and thus participate in internal cycling of TEIs. Both externally and internally derived particles participate in the removal of TEIs from the

water column through scavenging of dissolved TEIs, sinking, and burial in sediments (Jeandel et al., in press).

SPM in the ocean generally comprises three major biogenic phases: particulate organic matter (POM) and the biogenic minerals calcium carbonate (CaCO₃) and biogenic silica (BSi, also known as opal) (Bishop et al., 1977). In some ocean basins and near continental margins, abiotic components such as lithogenic material from atmospheric dust deposition or sediment resuspension and transport are also important. There are many more components that contribute to SPM, but they are rarely a significant fraction of the total SPM mass. In special circumstances such as near hydrothermal vents or sediments, oxyhydroxides of Fe and/or Mn can also be important (German and Von Damm, 2003; Macdonald and Gobeil, 2012).

Both particle concentration and composition affect scavenging of dissolved TEIs. Elevated particle concentrations provide more surfaces for scavenging, while different particle compositions may affect

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the particle affinity of a TEI. The role of SPM composition in TEI scavenging has been studied for the naturally occurring, strongly particle-reactive thorium isotopes (^{234}Th , ^{228}Th , and ^{230}Th), but there is not yet consensus over which phase exerts the most influence in scavenging. It has been variously proposed that the scavenging efficiency of ^{230}Th is controlled by CaCO_3 (Chase et al., 2002, 2003), lithogenic material (Luo and Ku, 2004; Roy-Barman et al., 2009), and/or Mn oxyhydroxides (Roy-Barman et al., 2005). All of these studies were conducted on sinking particles collected by sediment traps, where the identification of a single controlling factor can be confounded by fortuitous correlations between multiple factors (e.g., CaCO_3 and MnO_2 Roy-Barman et al., 2005), and may help explain the contradictory conclusions reached by various studies (Jeandel et al., in press; Roy-Barman et al., 2005). Indeed, most scavenging likely occurs onto small, suspended particles, which are more abundant, have more available surface area, and have a longer residence time in the water column than sinking particles. The particle dynamics that connect small, suspended particles onto which most scavenging occurs, to the large, sinking particles collected by sediment traps vary between different ecosystem types, potentially complicating the interpretation of sediment trap material.

Focusing on suspended particles allows a more direct study of the effect of particle composition on scavenging, without the complications of particle dynamics. Indeed, scavenging of particle-reactive TEIs has been studied on suspended particles collected by in-situ filtration (e.g., Bacon and Anderson, 1982), but not yet with the additional information provided by major particle composition. The addition of a sinking particle size class, either using size-fractionation during in-situ pumping, or pairing pumped samples (suspended particles) with sediment trap samples (sinking particles), additionally allows the study of particle dynamics that connect suspended and sinking particles through particle aggregation, disaggregation, and sinking (Cochran et al., 2000; Marchal and Lam, 2012; Murnane et al., 1994; Nozaki et al., 1987; Ohnemus and Lam, 2015). The relatively large volumes filtered (hundreds to thousands of liters) using in-situ filtration allows the measurement of many analytes on subsamples from the same filter, including various particle-reactive TEIs and all the major and minor phases of SPM, provided that care is taken to ensure even distribution of particles during sampling and processing (Bishop et al., 2012).

In addition to the effect of particle composition on scavenging, the mineral phases of SPM (i.e., CaCO_3 , opal, and lithogenic material) may help ballast POC to depth (Armstrong et al., 2002). Strong correlations are observed between POC and CaCO_3 flux in deep (> 2000 m) sediment traps (François et al., 2002; Klaas and

Archer, 2002), but similar correlations are typically not observed between shallow POC and CaCO_3 export flux at the base of the euphotic zone (Le Moigne et al., 2012). An increasing number of studies suggest that the observed ballast mineral correlations reflect underlying ecosystem control of POC flux to depth, for which the ballast minerals are simply proxies (Henson et al., 2012; Lam et al., 2011; Wilson et al., 2012). Further, studies have indicated regionally specific carrying coefficients of ballast minerals for POC (i.e., the regression coefficients for a multiple linear regression of POC flux as a function of CaCO_3 , opal, and lithogenic material) (Ragueneau et al., 2006; Wilson et al., 2012).

Here, we present the concentrations and major phase compositions of SPM in two size fractions (1–51 μm and > 51 μm) collected by in-situ filtration during the U.S. GEOTRACES North Atlantic Zonal Transect. The data presented here should be of use for investigating the effect of particle concentration and composition on the scavenging of particle-reactive TEIs, as well as allow examination of POC–ballast mineral correlations in the North Atlantic.

2. Methods

2.1. Cruise track and hydrography

The US GEOTRACES North Atlantic Zonal Transect was completed in two stages on the *R/V Knorr*: KN199-4 (hereafter “GT10”) departed from Lisbon, Portugal and ended in Cape Verde in October–November 2010 and sampled stations GT10-1 through GT10-12; KN204-1 (hereafter “GT11”) departed from Woods Hole, MA and ended in Cape Verde in October–December 2011 and sampled stations GT11-1 through GT11-24 (Fig. 1). Full ocean depth profiles of size-fractionated particles were collected by in-situ pumping at 8 stations on GT10 and 14 stations on GT11. Typical profiles were 16-depth resolution, with 8 depths in the upper 1000 m, and 8 depths between 1000 m and the ocean bottom. Pumps were programmed for 4 h of pumping, which resulted in a median of 461 L filtered through the Supor filter, and 1167 L filtered through the QMA filter.

The meridional component of the cruise track (GT10-1 to GT10-8), from Lisbon to the Mauritanian coast, is characterized by North Atlantic Central Water (i.e., relatively warm and salty waters between 20–30°W and 30–35°N that characterize the North Atlantic subtropical thermocline) in the upper 500 m, high salinity Mediterranean Outflow Waters between 500 and 1500 m, and North Atlantic Deep Water with some Antarctic Bottom Water

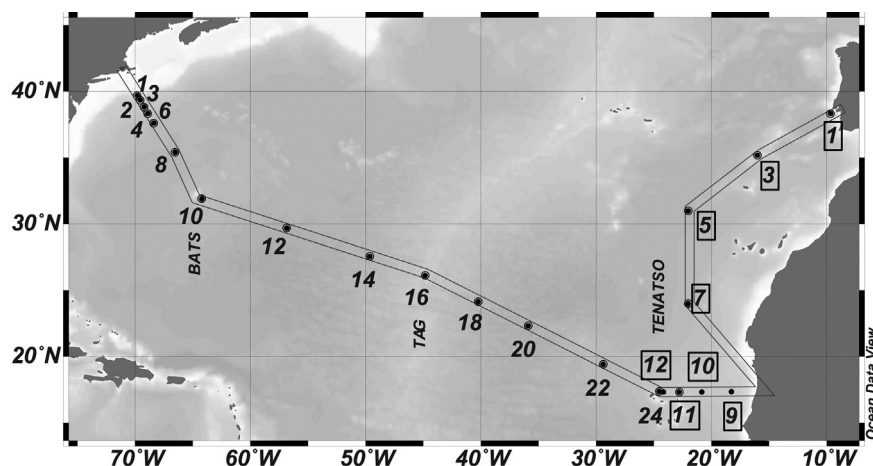


Fig. 1. Map of stations and section definition for US GEOTRACES North Atlantic Zonal Transect. Numerical annotations are station numbers for the GT10 and GT11 cruises. Station numbers from the first cruise, GT10, are boxed.

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