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Molecular and isotopic constraints on the sources of suspended particulate organic carbon on the northwestern Atlantic margin

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ABSTRACT

The abundance, carbon isotopic composition ($\Delta^{14}C$ and $\delta^{13}C$), and lipid biomarker (alkenones and saturated fatty acids) distributions of suspended particulate organic matter were investigated at three stations centered on the 2000, 3000, and 3500 m isobaths over the New England slope in order to assess particulate carbon sources and dynamics in this highly productive and energetic region. Transmissometry profiles reveal that particle abundances exhibit considerable fine structure, with several distinct layers of elevated suspended particulate matter concentration at intermediate water depths in addition to the presence of a thick bottom nepheloid layer at each station. Excluding surface water samples, the $\Delta^{14}C$ values of particulate organic carbon (POC) indicated the presence of a pre-aged component in the suspended POC pool ($\Delta^{14}C < +38‰$). The $\Delta^{14}C$ values at the 3000 m station exhibited greater variability and generally were lower than those at the other two stations where the values decreased in a more systematic matter with increasing sampling depth. These lower $\Delta^{14}C$ values were consistent with higher relative abundances of terrigenous long-chain fatty acids at this station than at the other two stations. Two scenarios were considered regarding the potential provenances of laterally transported POC: cross-shelf transport of shelf sediment ($\Delta^{14}C = -140‰$) and along-slope transport of the slope sediment proximal to the sampling locations ($\Delta^{14}C = -260‰$). Depending on the scenario, isotopic mass balance calculations indicate allochthonous POC contributions ranging between 15% and 54% in the meso- and bathy-pelagic zone, with the highest proportions at the 3000 m station. Alkenone-derived temperatures recorded on suspended particles from surface waters closely matched in-situ temperatures at each station. However, alkenone-derived temperatures recorded on particles from the subsurface layer down to 250 m were lower than those of overlying surface waters, especially at the 3000 m station, implying supply of phytoplankton organic matter originally produced in cooler surface waters. AVHRR images and temperature profiles indicate that the stations were under the influence of a warm-core ring during the sampling period. The low alkenone-derived temperatures in the subsurface layer coupled with the lower $\Delta^{14}C$ values for the corresponding POC suggests supply of OC on resuspended sediments underlying cooler surface waters distal to the study area, possibly further north or west. Taken together, variations in $\Delta^{14}C$ values, terrigenous fatty acid abundances, and alkenone-derived temperatures among the stations suggest that input of laterally advected OC is a

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prominent feature of POC dynamics on the NW Atlantic margin, and is spatially heterogeneous on a scale smaller than the distance between the stations (<150 km).

1. Introduction

Continental margins are highly productive oceanic environments, globally accounting for approximately 10–20% of marine primary productivity and 90% of organic carbon (OC) burial (Hedges, 1992; Behrenfeld and Falkowski, 1997). The dynamics of particulate organic carbon (POC) over continental margins is highly complex with strong spatial and temporal heterogeneity due to gradients in surface ocean productivity, nutrient supply, and current regimes. There is also potential for export of OC from the margins to the deep ocean (Walsh et al., 1981; Churchill et al., 1988; Druffel and Williams, 1990; Bauer and Druffel, 1998). The literature is replete with evidence to indicate the widespread transfer of OC from the continental margins to the ocean interior. This evidence includes: (i) increased material fluxes in deep, relative to shallow sediment traps deployed near continental slopes (Honjo et al., 1982; Biscaye et al., 1988; Freudenthal et al., 2001; Smith et al., 2001); (ii) high suspended particle concentrations in the bottom nepheloid layer or intermediate nepheloid layers detached from the upper slope (McCave, 1983; McCave et al., 2001); (iii) the importance of lateral particle transport of resuspended sediments in simulations of bottom- and intermediate-nepheloid layers in a regional ocean model (Karakaş et al., 2006); (iv) imbalances between carbon supply and oxygen consumption in sediments (Jahnke, 1996); (v) old ^{14}C ages of suspended and sinking POC (Druffel et al., 1998; Honda et al., 2000; Hwang et al., 2004); (vi) high aluminum contents of suspended particles (Sherrell et al., 1998); and (vii) the isotopic and molecular composition of organic matter in deep sea sediments (Benthien and Müller, 2000; Ohkouchi et al., 2002; Mollenhauer et al., 2006). Furthermore, the importance of long-range lateral transport of lithogenic material over and beyond the continental margin, known as hemipelagic deposition, in mineral input to the ocean interior has been well recognized (McCave and Tucholke, 1986; Rea and Hovan, 1995). Despite the evidence for widespread lateral transport, the magnitude of export, as well as the type of OC that is exported (i.e., as dissolved or particulate OC, and whether it is marine or terrestrial in origin), remains uncertain.

Redistribution of OC following initial deposition in margin sediments is important in determining the characteristics and quality of OC from several respects. It can re-expose OC to oxic degradation in the water column, enhancing biogeochemical transformations (Keil et al., 2004). Resuspension and across-shelf advection transports OC from more productive continental margins to ocean's interior (Walsh et al., 1981; Churchill et al., 1994; Karakaş et al., 2006), and may be important in export of terrestrial OC to abyssal depths and sequestration of this carbon in slope and basin sediments. Remobilization and lateral transport is also an important consideration for paleoclimate reconstruction from sediment since it can induce spatial and temporal effects between proxy records (Benthien and Müller, 2000; Ohkouchi et al., 2002; Mollenhauer et al., 2005).

The continental slope and rise of the NW Atlantic margin has been recognized as both a high productivity (Yoder et al., 2001; Mouw and Yoder, 2005) and high kinetic energy environment (Gardner and Sullivan, 1981; Hollister and Nowell, 1991). Both geological and physical oceanographic observations indicate that vigorous bottom currents are a common phenomenon in the region between the Gulf Stream and the Nova Scotian margin (Gardner and Sullivan, 1981; Hollister and McCave, 1984). These "benthic storms", which appear to be associated with the southward flowing deep western boundary current (DWBC), may scour, resuspend and laterally transport sedimentary particles over the slope. Remobilized particles may be entrained in the DWBC and settle out along its path when currents weaken or may be transported basinward through interactions between the DWBC and the deep recirculation gyres in the interior Atlantic basin where they can ultimately settle (McCave and Tucholke, 1986). Although lateral transport of particles from the northwest Atlantic margin to areas of accumulation in the deep Atlantic such as the Bermuda Rise has long been recognized, it has only been recently recognized that organic matter can also survive long-range transport to an extent that it can dominate carbon burial in pelagic sediments (Ohkouchi et al., 2002, submitted). Accumulation of allochthonous OC in Bermuda Rise sediments was revealed by the ^{14}C ages and composition of source-specific biomarker lipids. Notably, alkenones – unsaturated long-chain ketones derived from haptophyte algae – were up to 7000 ^{14}C-years older than planktonic foraminifera isolated from the same sediment horizon (Ohkouchi et al., 2002). Since both alkenones and planktonic forams grow in the surface water, they should have identical ages. The age offset thus indicates that formation of the algal biomarker must substantially predate that of the foram, and this observation can be explained by aging due to temporary storage in distal margin sediments or during transport. Moreover, measurements of the alkenone unsaturation index ($U^{k'}_{37}$; Prahl and Wakeham, 1987) suggested that alkenones were produced in colder surface waters than those overlying the Bermuda Rise (Ohkouchi et al., 2002). Stable hydrogen isotope (D) analysis of alkenones in Bermuda Rise sediments suggests that they were derived prominently from subpolar waters to the northwest or north of the drift (i.e., the Scotian Margin) (Englebrecht and Sachs, 2005). Together with available sedimentological information, the preponderance of evidence suggests supply of organic matter originating from the productive waters over the Northwest Atlantic margin.