



Ground-truthing the planktic foraminifer-bound nitrogen isotope paleo-proxy in the Sargasso Sea

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Abstract

We report the nitrogen (N) isotope ratios ($\delta^{15}\text{N}$) of planktic foraminifera collected from upper-ocean net tows (surface to 200 m), moored sediment traps, and core-top sediments at the Bermuda Time-series Site in the northern Sargasso Sea between 2009 and 2013. Consistent with previous measurements from low-latitude core-top sediments, the annually-averaged $\delta^{15}\text{N}$ of organic matter bound within the shells of euphotic zone-dwelling, dinoflagellate symbiont-bearing foraminifera collected in net tows (2.3‰ on average) approximates that of shallow thermocline (~200 m) nitrate (2.6‰), the dominant source of new N to Sargasso Sea surface waters. Deeper-dwelling foraminifer species without dinoflagellate symbionts tend to have a higher $\delta^{15}\text{N}$ (3.6‰ on average). We observe no systematic difference between the bulk tissue and shell-bound $\delta^{15}\text{N}$ in net tow-collected foraminifera. A decline in shell N content is observed from net tows (6.8 nmol/mg) to sediment traps (5.4 nmol/mg) and surface sediment (3.0 nmol/mg). On average, shell-bound $\delta^{15}\text{N}$ rises from net tows (3.1‰) to sediment traps (3.7‰) but does not change further upon incorporation into the sediments (3.7‰). Together, these observations are consistent with preferential loss of shells or shell portions with lower $\delta^{15}\text{N}$ and higher N content during sinking through the upper 500 m, followed by a non-isotope fractionating decrease in N content between sinking and burial. Time-series data from sediment traps (and to a lesser extent, surface net tows) exhibit seasonal $\delta^{15}\text{N}$ variations, with a minimum in early spring, a maximum in late spring and a decline from summer to fall. These variations appear to arise from seasonal changes in the $\delta^{15}\text{N}$ of total upper-ocean biomass, which are, in turn, driven by early springtime nitrate supply, subsequent nitrate drawdown, and an increase in the relative importance of ammonium recycling into the late summer and early fall. The $\delta^{15}\text{N}$ connection between total upper ocean biomass and foraminifera indicates that foraminifer-bound $\delta^{15}\text{N}$ records the $\delta^{15}\text{N}$ of the annual nitrate supply in oligotrophic (e.g., subtropical) environments but will also be sensitive to the degree of nitrate consumption in high-nutrient regions and possibly to changes in upper-ocean ammonium recycling under some conditions.

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1. INTRODUCTION

The accumulation of organic matter on the seafloor archives information about past ocean productivity and nutrient conditions, key factors controlling the influence of biology on atmospheric carbon dioxide concentrations and thus global climate. Organic nitrogen (N) in marine sediments and sedimentary microfossils is a promising recorder of the N isotopic composition of nitrate (NO_3^-) supplied to phytoplankton in oligotrophic environments such as the subtropical gyres, which is in turn affected by and thus bears witness to processes such as N fixation and denitrification (Altabet and Curry, 1989). In addition, the N isotopes are a potential recorder of surface water nitrate consumption in nitrate-replete environments such as the Southern Ocean (François et al., 1992; Altabet and François, 1994).

When nitrate is consumed by phytoplankton, the lighter ^{14}N isotope is preferentially incorporated, causing the remaining nitrate pool (and thus also the particulate organic N (PON) subsequently produced from it) to become progressively enriched in the heavier ^{15}N isotope (i.e., increasing in $\delta^{15}\text{N}$, where $\delta^{15}\text{N} = \{[(^{15}\text{N}/^{14}\text{N})_{\text{sample}} / (^{15}\text{N}/^{14}\text{N})_{\text{N}_2 \text{ in air}}] - 1\} \times 1000$; in units of per mil, ‰) (Wada and Hattori, 1978; Pennock et al., 1996; Waser et al., 1998; Sigman et al., 1999a). Thus, PON sinking to the seafloor carries with it the isotopic imprint of partial nitrate consumption in overlying waters. If the surface ocean nitrate pool is completely consumed, the $\delta^{15}\text{N}$ of the total accumulated PON converges on that of the initial nitrate supply. Thus, in oligotrophic environments where nitrate consumption in surface waters is always essentially complete, the $\delta^{15}\text{N}$ of sinking PON (and thus of N in underlying sediments) would be expected to match the $\delta^{15}\text{N}$ of the nitrate supply (Altabet, 1988; Altabet and François, 1994). Diagenetic alteration and/or exogenous N inputs, however, demonstrably influence the $\delta^{15}\text{N}$ of bulk sedimentary N (Altabet and François, 1994; Meckler et al., 2011) and have prompted a shift to analysis of N pools that are robust against these effects, with our focus here on microfossil-bound organic N (Sigman et al., 1999b; Robinson et al., 2004; Ren et al., 2009). With recent method developments, it is now feasible to analyze the N isotopes of the small amounts of organic N encased within the shells or ‘tests’ of planktic foraminifera (Ren et al., 2009; Ren et al., 2012; Straub et al., 2013), calcifying zooplankton that ubiquitously accumulate in deep-sea sediments.

Planktic foraminifera inhabit a wide range of ocean environments from the tropics to the poles and have a diversity of feeding habits. Shallow-dwelling species prey on zooplankton and larger phytoplankton, while deeper-dwelling species are sustained by detrital particles and/or the organisms that feed upon them (Bé et al., 1977; Spindler et al., 1984; Schiebel and Hemleben, 2017). Many shallower species also host algal symbionts: dinoflagellates in the case of most spinose, shallow-dwellers (Bé et al., 1977; Schiebel and Hemleben, 2017; and references therein), and other algae including chrysophytes in the case of some thermocline-dwellers (Gastrich, 1987; Faber et al., 1988). Foraminifera grow in size by adding chambers to their

shells, using an organic sheet as a template for calcification (King and Hare, 1972; Bé et al., 1979; Spero, 1988). In this way, N-rich biomineralizing proteins are added prior to each chamber addition and are sequestered within the calcite matrix (Bé et al., 1977; Hemleben et al., 1989). Additional calcification during life (ontogenic) and reproduction (gametogenic) may further protect shell-associated organic matter, while post-mortem encrustation might protect both shell-native and external organic matter. In the tropical and subtropical open ocean, there is a strong link between the $\delta^{15}\text{N}$ of thermocline nitrate, the main source of nitrate to the euphotic zone (i.e., the well-lit layer from the surface to the 1% light level) (Altabet, 1988; Knapp et al., 2005), and the shell-bound $\delta^{15}\text{N}$ of most planktic foraminifer species in underlying surface sediments (Ren et al., 2009; Ren et al., 2012), supporting the utility of the planktic foraminifer-bound $\delta^{15}\text{N}$ proxy. However, important questions remain regarding the controls on foraminifer-bound $\delta^{15}\text{N}$. First, how does shell-bound $\delta^{15}\text{N}$ compare to the $\delta^{15}\text{N}$ of foraminiferal tissue, and is this relationship stable? Second, are there other factors besides the $\delta^{15}\text{N}$ of the annual nitrate supply to the euphotic zone that affect foraminifer-bound $\delta^{15}\text{N}$, and are these adequately important to cause significant changes through time? Third, is the $\delta^{15}\text{N}$ signal acquired in the upper ocean preserved as tests sink to the seafloor? If shell-bound $\delta^{15}\text{N}$ is altered, is the magnitude of this alteration constant and/or systematic? To address these unknowns, we present modern foraminiferal tissue and shell-bound $\delta^{15}\text{N}$ measurements for a range of species collected from the upper ocean, sediment traps, and surface sediments at the Bermuda Time-series Site in the Sargasso Sea.

The Bermuda region has a well-characterised seasonal cycle of mixing and primary production (Steinberg et al., 2001; Lomas et al., 2013). The deepest mixing occurs in late winter/early spring (down to 200–250 m), injecting thermocline nitrate into surface waters. As the surface ocean warms and the mixed layer shoals in the late spring and early summer, nitrate is drawn down rapidly by phytoplankton to less than $0.1 \mu\text{M}$ (Lipschultz, 2001), and its concentration generally remains extremely low throughout the summer and early fall stratification period ($<0.01 \mu\text{M}$) (Fawcett et al., 2015). A gradual deepening of the mixed layer occurs in late fall and winter as the surface ocean cools and wind-driven mixing erodes the strong thermal gradient. Even during the period of deepest mixing, however, nitrate concentrations typically remain well below $0.5 \mu\text{M}$ in the upper 100 m, or $\sim 15\%$ of the concentration present at 200–250 m (Fig. 1). Therefore, nitrate consumption in this region is close to complete almost year-round (Lipschultz, 2001; Fawcett et al., 2015) and the $\delta^{15}\text{N}$ of PON sinking out of the euphotic zone should equal the $\delta^{15}\text{N}$ of the original subsurface nitrate supply (Altabet, 1988; François et al., 1992). This balance is only weakly affected by the export of dissolved organic N and suspended particles (Knapp et al., 2005). Thus, by focusing our ground-truthing efforts on the oligotrophic ocean, we have sought to initially minimize the complication of partial nitrate consumption. The Bermuda Time-series Site is typical of the oligotrophic, subtropical open ocean gyres

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