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Inorganic and organic sinking particulate phosphorus fluxes across the oxic/anoxic water column of Cariaco Basin, Venezuela

Claudia R. Benitez-Nelson [a,b,*], Lauren P. O'Neill Madden [b], Renée M. Styles [a], Robert C. Thunell [a,b], Yrene Astor [c]

[a] Department of Geological Sciences, University of South Carolina, Columbia, SC 29208, USA
[b] Marine Science Program, University of South Carolina, Columbia, SC 29208, USA
[c] Fundacion La Salle de Ciencias Naturales, Estacion de Investigaciones Marinas de Margarita, Isla de Margarita, Venezuela

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Abstract

Phosphorus (P) is a vital nutrient that is essential for all organisms and may limit growth on both modern and geologic timescales. The major removal mechanism of P from marine systems is via the transformation of dissolved P into sinking particulate P pools. Although most particulate P is remineralized before it reaches the seafloor, little is known about the processes that control its breakdown into dissolved phases. In this study, the P composition of sinking particles captured by five sediment traps distributed through the oxic and anoxic water column of the Cariaco Basin, Venezuela is examined. Samples were collected from January 1996 to December 2004. Total particulate P (TPP), particulate inorganic P (PIP), and particulate organic P (POP) fluxes varied considerably over the course of the nine year study, yet there were no significant seasonal differences in the overall flux of POP. In contrast, PIP, which comprises a major portion of TPP (averaging $52 \pm 19\%$ across all depths) had fluxes that were 30% higher during non-upwelling periods. Poor relationships between PIP and biologically derived constituents, e.g. particulate organic carbon (POC), suggest that most of this material was derived from non-biological sources, namely terrestrial runoff from rivers. Rapid remineralization of POP occurred relative to POC and PIP in oxic surface waters, whereas PIP was quickly remineralized relative to POC and POP in subsurface anoxic waters. This suggests a significant and alternating source of particulate P to the dissolved P pool that depends on oxygen availability. Thus, particulate P release to the dissolved phase and the upwelling of dissolved P into the euphotic zone is a potentially important positive feedback mechanism for enhanced primary production and carbon sequestration in continental margin sediments regardless of oxic versus anoxic conditions.

Keywords: Particulate flux; Particulate organic phosphorus; Particulate inorganic phosphorus; Continental margins; Sediment traps; Cariaco Basin

1. Introduction

Phosphorus (P) is one of the major nutrients utilized by all organisms. In the open ocean, regeneration of dissolved P compounds from sinking particles and the upwelling of these products to the euphotic zone is a critical step regulating P availability and biological production in surface waters (Thomson-Bulldis and Karl, 1998; Benitez-Nelson, 2000; Karl and Bjorkman, 2002; Paytan et al., 2003). Yet, little is known about the particulate P pool with regard to its composition and spatial and temporal variability. A major topic of debate

* Corresponding author. Department of Geological Sciences, University of South Carolina, Columbia, SC 29208, USA.
E-mail address: cbnelson@geol.sc.edu (C.R. Benitez-Nelson).

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is whether or not there is preferential remineralization of sinking particulate P relative to particulate organic carbon and nitrogen and whether this changes under oxic versus anoxic conditions (Knauer et al., 1979; Martin et al., 1987; Minster and Boulahdid, 1987; Anderson and Sarmiento, 1994; Benitez-Nelson, 2000; Karl and Bjorkman, 2002; Paytan et al., 2003). This debate is further confounded by increasing evidence that not all of the particulate P measured in sinking particles is organic in nature (Loh and Bauer, 2000; Benitez-Nelson et al., 2004; Faul et al., 2005). Rather, there appears to be a significant fraction that is inorganic, associated with non-biological sources, and potentially less bioavailable (Paytan et al., 2003; Faul et al., 2005).

The Cariaco Basin, located along the northern margin of Venezuela, is anoxic below ~275 m. Primary production occurs mainly within the upper 20–40 m of the mixed layer and most particle production occurs in the oxic zone (Thunell et al., 2000; Scranton et al., 2006). Therefore, it is an excellent place to examine particle regeneration in both oxic and anoxic waters. In this study, P concentrations and organic versus inorganic P speciation in sinking particles collected from five different depths in the water column between January 1996 and December 2004 are examined as part of the Cariaco Time Series Program (Müller-Karger et al., 2005).

2. Methods

The Cariaco Basin is a 1400-m-deep depression approximately 160 km long by 70 km wide located off the central Venezuelan coast (Fig. 1). It is connected to the Atlantic Ocean by a sill ~100-m-deep, and two slightly deeper channels that breech it; Canal Centinela (146-m-deep) and Canal de la Tortuge (135-m-deep). High surface production rates and restricted circulation result in anoxic waters below ~275 m. The depth of the oxycline varies between 250 and 320 m and is independent of density. Rather, fluctuations in oxycline depth appear to be due to lateral intrusions of Caribbean Sea water that are linked to eddies along the continental shelf (Astor et al., 2003).

Primary production in the Cariaco Basin varies seasonally and is driven by wind-induced coastal upwelling. As the Intertropical Conversion Zone (ITCZ) moves to its southern-most position, strong easterly/northeasterly trade winds develop between December and April (Thunell et al., 1999; Müller-Karger et al., 2000; Thunell et al., 2000; Müller-Karger

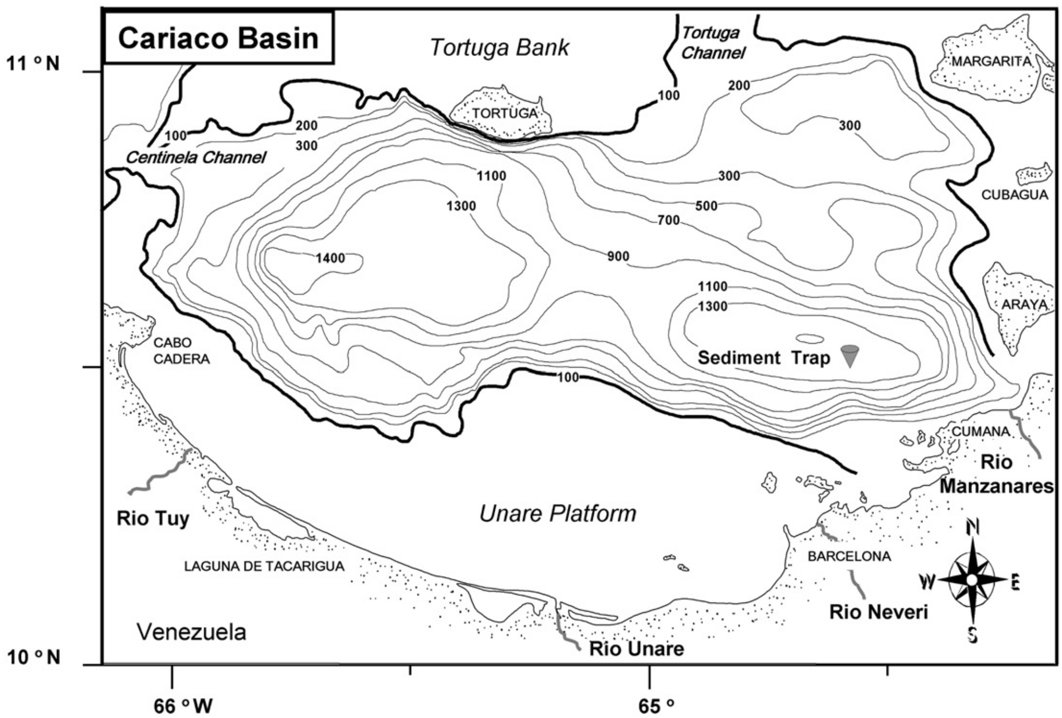

Fig. 1. Bathymetry of Cariaco Basin showing the location of the sediment trap array. Dark lines within the Basin depict the 100-m isobath. The four major rivers which drain directly into Cariaco Basin are denoted by the gray lines on the continent.