



ELSEVIER

Contents lists available at SciVerse ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

A new perspective on boundary scavenging in the North Pacific Ocean

Christopher T. Hayes^{a,b,*}, Robert F. Anderson^{a,b}, Samuel L. Jaccard^c, Roger François^d,
Martin Q. Fleisher^a, Maureen Soon^d, Rainer Gersonde^e^a Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, USA^b Department of Earth and Environmental Sciences, Columbia University, New York, NY, USA^c Geological Institute, Department of Earth Sciences, ETH Zürich, Switzerland^d Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada^e Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

ARTICLE INFO

Article history:

Received 6 August 2012

Received in revised form

12 February 2013

Accepted 8 March 2013

Editor: G. Henderson

Available online 19 April 2013

Keywords:

thorium

protactinium

scavenging

North Pacific Ocean

INOPEX

line P

ABSTRACT

Boundary scavenging, or the enhanced removal of adsorption-prone elements from the ocean in areas of high particle flux, is an often cited, though not well-quantified, concept used to understand the oceanic distribution of many trace metals. Because ^{230}Th and ^{231}Pa are produced uniformly from uranium decay and removed differentially by scavenging, the process of boundary scavenging can be elucidated by a more detailed knowledge of their water column distributions. To this end, filtered seawater was collected across the gradients in particle flux which span the subarctic Pacific: in the west during the Innovative North Pacific Experiment (INOPEX) and in the east along Line P. Lateral concentration gradients of dissolved ^{230}Th are small throughout the subarctic Pacific at 12 sites of variable particle flux. This contradicts the prediction of the traditional boundary scavenging model. A compilation of water column data from throughout the North Pacific reveals much larger lateral concentration gradients for ^{230}Th between the subarctic North Pacific and subtropical gyre, over lateral gradients in scavenging intensity similar to those found within the subarctic. This reflects a biogeochemical-province aspect to scavenging. Upper water column distributions of ^{231}Pa and $^{231}\text{Pa}/^{230}\text{Th}$ ratio are consistent with the influence of scavenging by biogenic opal, while deep waters (> 2.5 km) reveal an additional ^{231}Pa sink possibly related to manganese oxides produced at continental margins or ridge crests.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Boundary scavenging (Bacon et al., 1976; Spencer et al., 1981) is a classic mechanism used to understand the cycling of chemical elements having the tendency to adsorb onto sinking particles, or to be scavenged. Scavenging (Goldberg, 1954) affects the cycling of many trace elements from micronutrients, such as Fe (Boyd and Ellwood, 2010) or Co (Bown et al., 2011), to tracers of dust deposition, such as Al (Measures and Vink, 2000) or Th (Hsieh et al., 2011). It is therefore valuable to better understand the nature of the boundary scavenging process.

The boundary scavenging mechanism predicts that those elements whose residence times are long enough to allow basin-wide isopycnal diffusion (> 100 yr), such as Pa, will be transported away from areas of low scavenging intensity to be removed in areas of high scavenging intensity (often associated with ocean boundaries) (Bacon, 1988). This lateral transfer reduces the

concentration difference between ocean margin and ocean interior imposed by differential scavenging intensities. An element like Th, on the other hand, whose residence time (< 50 yr) is short enough to limit isopycnal transport, should therefore display concentrations which scale inversely with scavenging intensity. More detailed accounts of the development of boundary scavenging are given elsewhere (Anderson et al., 1990; François, 2007; Roy-Barman, 2009; Rutgers v. d. Loeff and Geibert, 2008), but few historical data exist to elucidate it in the dissolved phase of the water column. The prime objectives of this study are to relay new measurements of dissolved ^{230}Th and ^{231}Pa throughout the North Pacific and offer a new perspective on the traditional boundary scavenging concept.

The North Pacific Ocean lacks active deep water formation, which is known to influence $^{231}\text{Pa}/^{230}\text{Th}$ distributions in the Atlantic where surface waters of low radionuclide concentration are injected to depth (Luo et al., 2010; Moran et al., 2002). We cannot, however, discount quantitatively the influence of the Pacific Meridional Overturning Circulation (PMOC) on dissolved $^{231}\text{Pa}/^{230}\text{Th}$ in the North Pacific, namely the northward inflow of Lower Circumpolar Deep Water (LCDW) and upwelling to form southward flowing North Pacific Deep Water (NPDW). We defer to

* Correspondence to: Comer 427, 61 Route 9W, Palisades, NY 10964, USA.
Tel.: +1 845 365 8572; fax: +1 845 365 8155.

E-mail address: cth@ldeo.columbia.edu (C.T. Hayes).

modeling studies for a more complete treatment of PMOC (Luo et al., 2012) but signify in our work where the influence of overturning may be important. Aside from overturning, we expect ^{231}Pa and ^{230}Th distributions to be determined by the balance between production due to U decay, removal by scavenging, and redistribution by mixing. Below we elaborate on how we approach each of these terms.

The uniform distribution of ^{235}U and ^{234}U (Andersen et al., 2010; Delanghe et al., 2002; Robinson et al., 2004; Weyer et al., 2008) amounts to a constant and uniform production for ^{231}Pa and ^{230}Th , respectively, throughout the ocean. The production term, P , depends on the seawater concentration of U, which as a conservative element, varies with salinity (Chen et al., 1986).

Our basis for understanding scavenging is the one-dimensional reversible-scavenging model (Bacon and Anderson, 1982). Neglecting lateral inputs, this model predicts a linear increase with depth (z) for the concentration of dissolved (C_d) and particulate (C_p) phases for *in-situ*-produced scavenged elements. Given a group of small particles, which assumedly carry most of the scavenged element and sink at a constant speed, S , the concentrations are

$$C_d \cong \frac{Pz}{SK} \quad (1)$$

$$C_p = \frac{Pz}{S} \quad (2)$$

C_d and C_p are expressed in units per volume of seawater. K is the distribution coefficient between particulate and dissolved phases (c_p/c_d), which may vary as a function of particle concentration or particle composition. If lateral effects can be neglected, distributions of C_d , the primary subject of study here, are expected to respond inversely to scavenging intensity, parameterized by SK .

When spatial concentration gradients exist, mixing by eddy diffusion will transport radionuclides from areas of high concentration to areas of low concentration. However, for the case of scavenged elements, one must consider the timescale (Δt) required for mixing to take place over a certain length scale (Δx) against the residence time (τ) of the element or isotope in question. Spatial concentration gradients will be undisturbed if $\Delta t \gg \tau$. On the other hand, imposed gradients could be mixed away if $\Delta t \ll \tau$. In one-dimension, as presented by Roy-Barman (2009), the root-mean-square displacement ($\sqrt{(\Delta x)^2}$, given here for simplicity

as Δx) of a randomly walking water parcel is

$$\Delta x = \sqrt{2K_{mix}\Delta t} \quad (3)$$

where K_{mix} is the coefficient of eddy diffusion. Following Okubo et al. (2012), when substituting Δt by τ , Δx then represents the maximum length scale over which mixing influences spatial concentration gradients. Typical values in the North Pacific of isopycnal (lateral), K_H , and diapycnal (vertical), K_V , eddy diffusivity are $10^3 \text{ m}^2 \text{ s}^{-1}$ and $10^{-4} \text{ m}^2 \text{ s}^{-1}$, respectively (Kawabe, 2008).

The mixing length-scale argument calls for an appropriate definition of τ . Assuming steady-state, neglecting advective or diffusive inputs, the residence time of dissolved ^{230}Th (^{231}Pa) at any point is given by its concentration divided by the sum of its *in situ* sources: production via uranium decay and desorption, the latter of which unfortunately cannot be characterized with measurements of only C_d . Alternatively, the inventory of C_d from the surface to some depth divided by the depth-integrated P results in the average time a dissolved nuclide resides in the integrated water column before being removed to deeper water by scavenging, irrespective of desorption within that depth zone. We find this integrated residence time to be most appropriate when considering the influence of mixing on dissolved nuclide distributions in the absence of constraints on desorption. Nonetheless, this residence time is not independent of advective or diffusive inputs where they exist. The integrated residence time will be an overestimate at locations which receive ^{230}Th (^{231}Pa) by circulation and an underestimate at locations where ^{230}Th (^{231}Pa) is removed by circulation.

2. Materials and methods

2.1. Dissolved Th (Pa) sampling and analysis

The new data presented here were produced by groups at the Lamont-Doherty Earth Observatory (L-DEO) and the University of British Columbia (UBC). Seven profiles of dissolved ^{230}Th , ^{231}Pa , and ^{232}Th from the SO202-INOPEX cruise of July–August 2009 (Gersonde, 2012) (SO202-stations in Fig. 1) were produced at L-DEO. Five profiles of dissolved ^{230}Th from the eastern subarctic Pacific collected in summer 2006 (P and Z stations in Fig. 1, referred to collectively as Line P in the text) were produced at UBC.

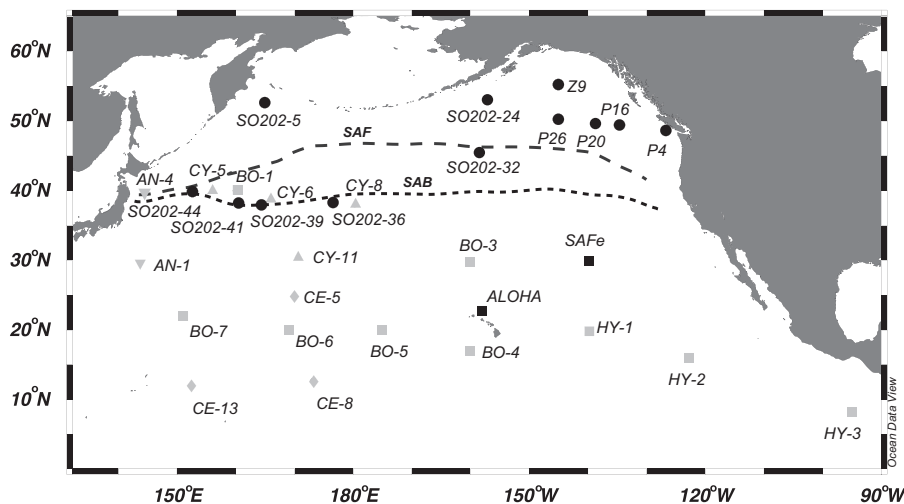


Fig. 1. Map of station locations for dissolved radionuclide data presented in the paper (black circles and squares) and those for which total radionuclide data has been reported: gray triangles (Nozaki et al., 1981), gray diamonds (Nozaki and Nakanishi, 1985), gray inverted triangles (Nozaki et al., 1998), and gray squares (Okubo et al., 2012). Dashed and dotted lines approximate the subarctic front (SAF) and subarctic boundary (SAB), respectively, as drawn by Harrison et al. (2004). SO202- refers to the INOPEX cruise; P and Z stations refer to the Line P cruise (see Section 2.1).

Download English Version:

<https://daneshyari.com/en/article/4677095>

Download Persian Version:

<https://daneshyari.com/article/4677095>

[Daneshyari.com](https://daneshyari.com)