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Seasonal changes in thorium scavenging and particle aggregation in the western Arctic Ocean

K. Lepore*, S.B. Moran

Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882-1197, USA

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Abstract

Seasonal changes in Th scavenging and particle aggregation were determined along two shelf-basin transects in the western Arctic Ocean during the spring (May–June) and summer (July–August) of 2002 and 2004. Measurements of dissolved and particulate ^{234}Th and ^{228}Th activities were used to quantify Th residence times and reversible rates of Th sorption and particle aggregation. Prior to the spring bloom in 2002, ^{234}Th and ^{228}Th residence times were equal and Th scavenging was concordant, indicating predominately steady-state conditions. In contrast, scavenging of ^{234}Th and ^{228}Th in the summer of 2002 and the spring and summer of 2004 was discordant, indicating a departure in scavenging rates from steady-state conditions during periods of seasonally high biological activity and particle export. Rates of particle aggregation and disaggregation were calculated using a one-dimensional reversible exchange model and ^{234}Th and ^{228}Th activities in small (1–53 μm) and large (>53 μm) particles. Maximum rates were determined coincident with the chlorophyll maximum (25–100 m) and increased by an order of magnitude between periods of low and high productivity. These Th measurements provide evidence that seasonally enhanced rates of particle aggregation might increase the magnitude of the particulate organic carbon (POC) flux in this Arctic regime.

Keywords: Arctic; Thorium isotopes; Scavenging; Particle aggregation

1. Introduction

The Arctic Ocean is characterized by a marked spatial and seasonal heterogeneity in the abundance, geochemical composition, and sinking flux of particles (Stein and Macdonald, 2004). This heterogeneity is due to both the wide range in primary productivity, from extremely low values in the central Arctic of $10\,g\,C\,m^{-2}\,yr^{-1}$ to values of $400\,g\,C\,m^{-2}\,yr^{-1}$ during the summer in the Chukchi Sea (Gosselin et al., 1997; Hill and Cota, 2005; Walsh and Dieterle, 1994), and to the substantial terrigenous input of material along the extensive continental margins (Gordeev, 2000; Gordeev et al., 1996). Large seasonal and spatial shifts in particle composition and abundance observed in the Arctic Ocean might affect rates of particle aggregation and disaggregation and hence the transfer efficiency of reduced carbon from the euphotic zone to the deep waters of the shelf/slope and interior basins. In turn, changes in particle–particle interaction rates may

*Corresponding author. Present address: School of Physics, University College Dublin, Belfield Dublin 4, Ireland.
Tel.: +1 353 1 716 2432; fax: +1 353 1 283 7275.
E-mail address: Kate.Lepore@ucd.ie (K. Lepore).

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alter the benthic biological community structure as well as sediment geochemical processes.

Thorium isotopes have been used extensively as geochemical tracers throughout the global ocean (Bacon and Anderson, 1982; Bacon and Rutgers van der Loeff, 1989; Buesseler et al., 1992a; Clegg et al., 1991; Coale and Bruland, 1985; Cochran, 1982; Cochran and Masque, 2003; Nozaki et al., 1987). Measurements of Th isotopes can provide information on the rates and mechanisms of a number of oceanic processes, including particle export and settling velocities, rates of particle aggregation and disaggregation, and residence times of particle–reactive pollutants (Bacon and Anderson, 1982; Bacon et al., 1989; Clegg et al., 1991; Cochran et al., 1993; Kaufman et al., 1981; Li et al., 1979; Moran and Buesseler, 1992; Moran and Buesseler, 1993; Nozaki et al., 1981). Several recent studies have used short-lived Th isotopes as tracers of particle export and scavenging in the Arctic Ocean (Amiel et al., 2002; Baskaran et al., 2003; Chen et al., 2003; Coppola et al., 2002; Lepore et al., 2006a; Moran et al., 1997, 2005; Moran and Smith, 2000; Trimble and Baskaran, 2005; Trimble et al., 2004). Results from these field investigations indicate a wide range in the rate of particle export and Th scavenging that may be attributed to differences in particle concentration, source, and sinking flux throughout the Arctic Ocean.

The goal of this study is to characterize the spatial and seasonal variability in particle cycling rates along a series of shelf–basin transects occupied during the spring and summer of 2002 and 2004 (Fig. 1). Simultaneous measurement of dissolved and particle size-fractionated ^{234}Th and ^{228}Th permits the calculation of forward and reverse rates of exchange, scavenging residence times, and rates of particle aggregation and disaggregation. These seasonal data were also used to assess the temporal change in Th sorption and particle aggregation in this shelf/slope region. ^{228}Th and ^{228}Ra activities are reported in this paper; ^{234}Th and ^{238}U activities discussed here are reported elsewhere (Lepore et al., 2006a; Moran et al., 2005).

2. Methods

2.1. Sample collection and analysis

Samples were collected in the Chukchi Sea on board the U.S.C.G.C. *Healy* as part of the Shelf–Basin Interactions (SBI) Phase II field program. Samples were collected for analysis of ^{234}Th and ^{228}Th during the spring (May 5–June 12, 2002; May 15–June 23, 2004) and summer (July 21–August 18, 2002; July 17–August 26, 2004) along two shelf–basin transects in the Chukchi Sea, Arctic Ocean (Fig. 1).

Large-volume samples (200–1000 L) were collected using battery-operated in situ pumps (Challenger Oceanic Systems and Services, UK; McLane Laboratories, USA) at a flow rate of 2–4 L min^{-1}. Seawater was passed sequentially through one or a series of 142 mm Nitex screens held in PVC filter holders (53 μm at all depths during 2002 and 2004; 20, 53, and 100 μm at 50 and 100 m during 2004), a 1 μm prefilter cartridge, and two MnO_2-impregnated cartridges connected in series to scavenge dissolved Th. Prefilter and MnO_2 cartridges were dried at 60 °C and ashed at 500 °C at sea.

2.2. ^{234}Th Analysis

Dissolved and particulate ^{234}Th activities have been reported, and a detailed description of the measurement techniques can be found elsewhere (Lepore et al., 2006a; Moran et al., 2005). Cartridge collection efficiencies were calculated from ^{234}Th activities on the first and second MnO_2 cartridges (average = 75 ± 22%) and used to calculate dissolved ^{228}Th activities.

2.3. ^{228}Th analysis

Samples were selected from the West Hanna Shoal (WHS) and Barrow Canyon (BC) transects from the spring and summer of 2002 and 2004 and analyzed for ^{228}Th following ^{234}Th analysis (Table 1). Thorium was isolated from Ra and other radionuclides with a series of ion exchange columns (AG1-X8 strong anion exchange resin; BioRad Laboratories, Hercules, CA) followed by electrodeposition on a stainless steel planchet (Buesseler et al., 1992b). ^{228}Th activities were measured with a Canberra Alpha Analyst alpha counter (S570). A known amount of ^{229}Th (~0.5 dpm) was added prior to Th separation to determine the chemical recovery (average = 77 ± 19%). To calculate ^{228}Th ingrowth from ^{228}Ra decay between the time of sample collection and Th–Ra separation, Ra effluent from the ion exchange purification was collected and stored for approximately 6 months to 1 yr, after which time ingrown Th was separated from Ra a second time with ion exchange