Continental Shelf Research 75 (2014) 68–75

Contents lists available at ScienceDirect

Continental Shelf Research

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

Research papers

Recent organic carbon accumulation (~100 years) along the Cabo Frio, Brazil upwelling region

Christian J. Sanders [a,*,1], Pedro P. Caldeira [b], Joseph M. Smoak [c], Michael E. Ketterer [d,2], Andre Belem [a], Ursula M.N. Mendoza [a], Lívia G.M.S. Cordeiro [a], Emmanoel V. Silva-Filho [a], Sambasiva R. Patchineelam [a], Ana Luiza S. Albuquerque [a]

[a] Universidade Federal Fluminense, Departamento de Geoquímica, Rua Outeiro São João Baptista S/N, Morro do Valonginho, Niterói-RJ 24020-141, Brazil
[b] Departamento de Biofisica, Universidade Federal do Rio de Janeiro, Instituto de Biofísica Carlos ChagasFilho, Avenida Carlos Chagas Filho, Rio de Janeiro – RJ 21941-902, Brazil
[c] Department of Environmental Science, Policy and Geography, University of South Florida, St. Petersburg, FL 33701, USA
[d] Department of Chemistry and Biochemistry, Northern Arizona University, Box 5698, Flagstaff, AZ 86011-5698, USA

ARTICLE INFO

Article history:
Received 4 April 2013
Received in revised form
7 September 2013
Accepted 15 October 2013
Available online 30 October 2013

Keywords:
Sedimentation
Organic sediments
^{210}Pb and $^{239+240}$Pu geochronology
δ^{13}C
TOC/TN molar ratio
Lateral transport

ABSTRACT

Six sediment cores were obtained from the Cabo Frio shelf region of coastal Brazil to quantify the accumulation of organic carbon in a highly productive upwelling region. The sampled locations, 10–60 km offshore at ~100 m water depth, were investigated for excess ^{210}Pb (^{210}Pb$_{ex}$) as well as $^{239+240}$Pu fallout activities to determine sedimentary dynamics. The ^{210}Pb$_{ex}$ and $^{239+240}$Pu dating models show that the sediment accumulation rates varied substantially throughout this complex hydrodynamic system (0.8–5.5 mm yr^{-1}). Excess ^{210}Pb and $^{239+240}$Pu fluxes indicate lateral transport, with varying intensity along the continental shelf. The stations with the greatest ^{210}Pb$_{ex}$ and $^{239+240}$Pu sediment inventories are also the sites with the highest carbon accumulation rates (CAR). The total organic carbon (TOC) and total nitrogen (TN) contents, along with the δ^{13}C results, indicate that the organic matter deposited in this region is mainly of marine origin. The results of this work suggest that lateral transport, with varying intensity along the shelf, contribute to the large quantities of marine plankton buried at specific depositional settings in the Cabo Frio upwelling region (~1–8 mol of OC cm^{-2} yr^{-1}).

1. Introduction

The ocean accounts for almost half of the world's net annual photosynthesis, much of which is produced on or near continental shelves (Burone et al., 2011; Muller-Karger et al., 2005; Thunell et al., 2007). Upwelling areas near the continental shelf are known for particularly high primary production rates, as these areas are fueled by the advection of nutrient-rich waters (Blanco et al., 2001; Muller-Karger et al., 2005; Niggemann et al., 2007; Thunell et al., 2007). The upwelled nutrient-rich water either moves across the shelf through lateral circulating processes or is retained shoreward of the shelf break (Jahnke et al., 1990).

Oceanic inputs through wind-driven processes such as eddies associated with boundary currents are typical in coastal upwelling systems (Jahnke et al., 1990; Thunell et al., 2007). These systems are influenced by western boundary currents such as the Brazil Current (BC) along with eddy interactions (Belem et al., 2013). Because the biological productivity and associated high particle fluxes are mostly shoreward of the shelf break, sinking particles tend to accumulate more efficiently in shelf sediments. The burial efficiency of organic carbon (OC) is enhanced by the shallow water column and rapid rate of sediment accumulation (Smoak et al., 1999). The production of OC in these systems is directly influenced by upwelling as the shallow water depths of continental shelves extend to the slope, favoring the production and accumulation of organic-rich sediments (Baumgart et al., 2010; Burone et al., 2011; Niggemann et al., 2007). Many of the physical processes along upwelling regions enhance primary production and facilitate the downward flux of settling particles (Antoine et al., 1996; Fischer et al., 2000). Understanding the processes that control accumulation of OC in sediments from upwelling regions is of significance when characterizing the processes involved in the marine organic carbon cycle (Baumgart et al., 2010; Jahnke et al., 1990).

The objectives of this study are to quantify recent organic carbon accumulation rates through ^{210}Pb$_{ex}$ and $^{239+240}$Pu profiles,

* Corresponding author.
E-mail addresses: christian.sanders@scu.edu.au, zinosanders@yahoo.com (C.J. Sanders).
[1] Current address: Centre for Coastal Biogeochemistry Research, School of Environment, Science and Engineering, Southern Cross University, P.O. Box 157, Lismore, NSW 2480, Australia.
[2] Current address: Department of Chemistry, Metropolitan State University of Denver, PO Box 173362, Campus Box 52, Denver, CO 80217-3362, USA.

0278-4343/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.csr.2013.10.009

and to indicate the sources of deposited organic matter using total organic carbon measurements (TOC), total nitrogen (TN) and $\delta^{13}C$. We hypothesize that lateral transport is an important mechanism influencing the organic carbon accumulation rates (CAR) along the Cabo Frio continental shelf. Fluxes and sediment inventories of $^{210}Pb_{ex}$ and $^{239+240}Pu$ are used to examine this hypothesis.

2. Site description

The Cabo Frio upwelling zone is dominated by two principal oceanographic, physiographic and geomorphological systems. One is the Brazil current (BC) which flows along the Brazilian southeastern coast including an area of active upwelling between Cabo Frio (23°S) and Cabo de Santa Marta (28°S). The other is marked by the upwelling of the South Atlantic Central Water (SACW), both near the coastal zone and over the continental shelf. The continental shelf is characterized by two distinct bathymetric surfaces, one approximately 50 m deep and extending 5 km offshore and a second ranging from 90 and 130 m deep and extending from 5 to 100 km offshore to the shelf break (Campos et al., 2000; Valentin et al., 1987).

The coastal upwelling of the SACW directly influences the maximal primary production near the Cabo Frio shelf break (Burone et al., 2011; Sumida et al., 2005; Yoshinaga et al., 2010), though these events may shift in accordance with climatic factors (Souto et al., 2011) and references therein). The primary productivity in this upwelling zone has been documented to be between 188 and 520 g m^{-2} yr^{-1} of organic matter (Burone et al., 2011). This value is in agreement with the primary production values in other upwelling regions of the world (Baumgart et al., 2010; Muller-Karger et al., 2005; Niggemann et al., 2007; Thunell et al., 2007).

3. Materials and methods

3.1. Geophysical survey

The geophysical survey included seismic profiling with an operating frequency of 3.5 kHz using the Geopulse Geoacoustics system. For the echo-character depth calculations, a speed of 1500 m/s through the sediments was assumed. The high-resolution seismic bathymetric survey covered a total area of 680 km^2 within the framework of SE-NW and NE-SW configurations (Fig. 1). Based on the geophysical survey, six box-cores were collected across the shelf within the 680 km^2 mud bank (Fig. 1), formed by transgressive–regressive events during the Last Glacial Maximum, and favored by the position of the quasi-stationary Cabo Frio eddy. Sediment cores were sub-sampled by using PVC tubes (∅=10 cm, 40 cm length). The sediment cores were collected in an attempt to best represent the Cabo Frio upwelling region (~100 m depth), where the SACW and BC currents meet (Fig. 1).

3.2. Radionuclide analyses

For $^{210}Pb_{ex}$ analyses, sediment cores were sectioned at 1 cm intervals. Sediments from each interval were sealed in 70 mL Petri dishes for at least three weeks to establish secular equilibrium between ^{226}Ra and its daughters ^{214}Pb and ^{214}Bi. Gamma spectrometric measurements were conducted by using a semi-planar intrinsic germanium high purity coaxial detector with 40% efficiency, housed in a lead shield, coupled to a multichannel analyzer. Activities of ^{210}Pb were determined by the direct measurement of 46.5 keV photopeak, while ^{226}Ra activities were obtained by averaging peaks from the daughters ^{214}Pb and ^{214}Bi (295.2 keV, 351.9 keV and 609.3 keV) (Moore, 1984). The excess ^{210}Pb ($^{210}Pb_{ex}$) activity was estimated by subtracting the ^{226}Ra from the total ^{210}Pb activity. Samples were counted for at least 86,000 s in identical geometrical cylinders. Self-absorption corrections were calculated following the method of (Cutshall et al., 1983). The sediment accumulation rates (SAR) were obtained through the Constant Initial Concentration (CIC) dating method (Appleby and Oldfield, 1992), as $^{210}Pb_{(ex)}$ was fitted via the least squares procedure and the slope of the log-linear curve was used to calculate the SAR.

For $^{239+240}Pu$ measurements, the procedures followed were based upon procedures given in (Ketterer et al., 2004) and (Sanders et al., 2010). Dried, pulverized sediment sub-samples of ~10 g were dry-ashed overnight at 600 °C for 16 h, and leached in a 40 mL glass vial with 20 mL of 16 M HNO_3. The leaching was conducted overnight at 80 °C with added ^{242}Pu yield tracer (NIST 4334 g, 44.6 pg). Acid leaching (as opposed to complete

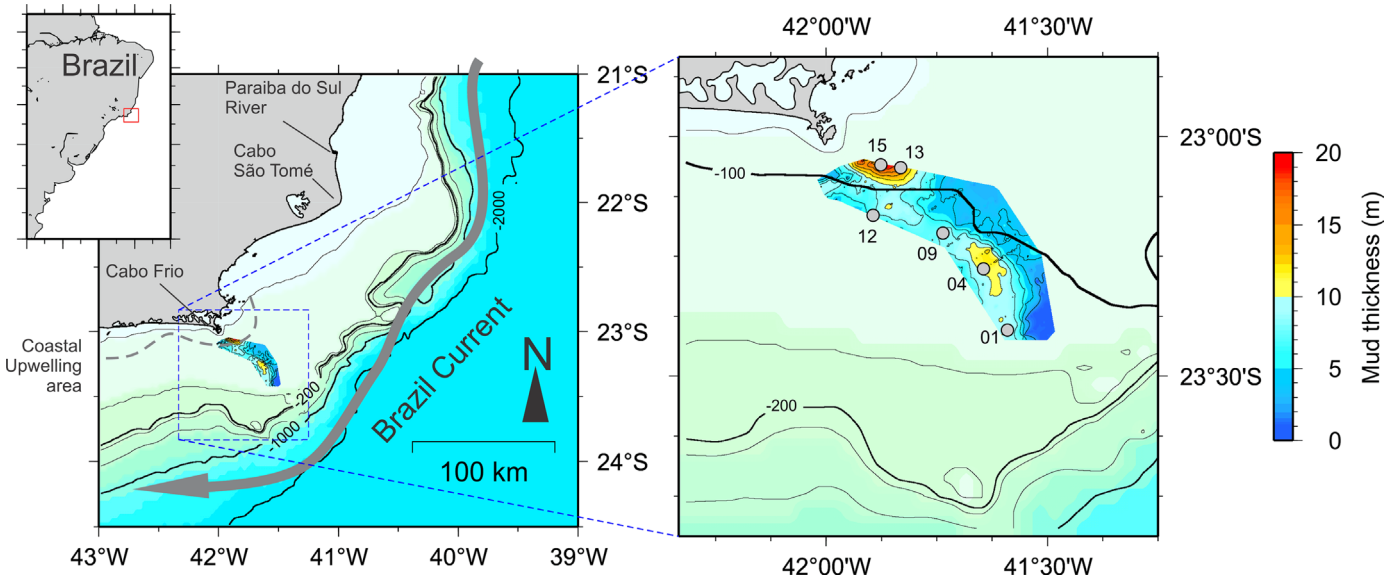

Fig. 1. Study stations along the Cabo Frio continental shelf where the six box-cores were collected.