Palaeogeography, Palaeoclimatology, Palaeoecology 408 (2014) 1–10

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Mid-to-Late Holocene organic carbon export variability at the southern boundary of the California Current: An approach based on diffuse spectral reflectance of marine sediment cores

Aleix Cortina [a,b,*], Juan Carlos Herguera [c]

[a] Department of Geology, University of Salamanca, 37008 Salamanca, Spain
[b] Institute of Earth Sciences, Université de Lausanne, CH-1015 Lausanne, Switzerland
[c] Oceanología, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), 22860 Ensenada, Mexico

ARTICLE INFO

Article history:
Received 30 July 2013
Received in revised form 20 March 2014
Accepted 27 April 2014
Available online 5 May 2014

Keywords:
Diffuse spectral reflectance
Organic carbon
California Current System
Holocene
El Niño/Pacific Decadal Oscillation (PDO)

ABSTRACT

Here we present the results obtained from diffuse spectral reflectance (DSR) on the visible wave spectra on a 4.5 m-long Calypso Kasten core (MD02-2506-C^2), collected from the San Lázaro Basin (SLB), with the aim of reconstructing the Mid-to-Late Holocene variability in export production in the California Current System (CCS). We applied an R-mode maximum likelihood factor analysis on the first derivative of the diffuse spectral reflectance. We then compared the factor scores obtained with this method and the organic carbon (OC) content of the core in order to establish a statistical transfer function between both variables. We eliminated high-frequency noise with the aid of Singular Spectral Analysis (SSA) from both records, increasing the correlation between both variables ($r = -0.71$, $p < 0.001$). These results indicated that DSR can be used as a reliable proxy of the OC content in high-resolution SLB sediments, which we used to reconstruct past CCS organic carbon export variability. Our findings suggest changes in organic carbon production and export from the Mid-to-Late Holocene, most likely resulting from changing influences on the SLB due to the interaction of the Pacific Decadal Oscillation (PDO) and *El Niño*.

1. Introduction

The methods most commonly used to determine organic carbon in marine sediments involve chemical analysis: (1) wet oxidation of organic carbon (Froelich et al., 1971) and (2) analysis of the residue for total carbon after acid treatment to eliminate $CaCO_3$ (Gibbs, 1977). These analyses are time-consuming, expensive and destructive. Alternatively, by using sediment color derived from DSR techniques it is possible to rapidly obtain quasi-continuous and non-destructive records at high-resolution. Recent studies have tested the reliability of using DSR (Balsam and Deaton, 1991, 1996; Ortiz et al., 1999; Ortiz et al., 2004) and colorimetric parameters (L*a*b) (Balsam et al., 1999) as proxies to interpret past oceanographic conditions from marine sediment cores. Among these works, the study carried out by Ortiz et al. (2004) on a marine sediment core retrieved in Magdalena Basin, south of the CCS is of great interest. They performed a principal component analysis (PCA) on first derivative values of the visible reflectance spectrum obtained with a portable spectrophotometer, a Minolta CM-2022. From the PCA they extracted three factors, of which factors 1 and 3 were determined to represent calcium carbonate and organic carbon respectively in the interval from 30 kyr to 50 kyr, when climatic oscillations were very pronounced. Although previous studies have demonstrated the reliability of DSR as a method to identify marine sediment compounds, further development is necessary in order to quantify these compounds and to apply this methodology under more stable conditions (e.g. Holocene).

The San Lázaro Basin (SLB) is situated in the southern part of the Baja California Peninsula (Fig. 1), close to the dynamic boundary between the cooler California Current waters from the north and the warm waters of the tropical Pacific from the south, which makes it an ideal location to explore the climatic teleconnections between the western North American continental climate and the climate of the equatorial Pacific during the Holocene.

The seasonal changes in the intensity of advective processes in the California Current System (CCS) are mainly controlled by the position of two main pressure centers in the northeastern Pacific: (1) the Aleutian Low (AL) in the mid-latitude North Pacific during winter and, (2) the North Pacific High (NPH), centered in the subtropical North Pacific during spring to summer (Fleming et al., 1987). At present, the spring intensification of the CCS is driven by the pressure gradient between the NPH and the continental low that fuels the northwesterly winds that trigger upwelling processes in this eastern boundary current (EBC), bringing relatively cooler and nutrient rich waters to the surface that sustain the relatively high levels of primary productivity in this

* Corresponding author.
E-mail addresses: acortina@usal.es (A. Cortina), herguera@cicese.mx (J.C. Herguera).

http://dx.doi.org/10.1016/j.palaeo.2014.04.015
0031-0182/

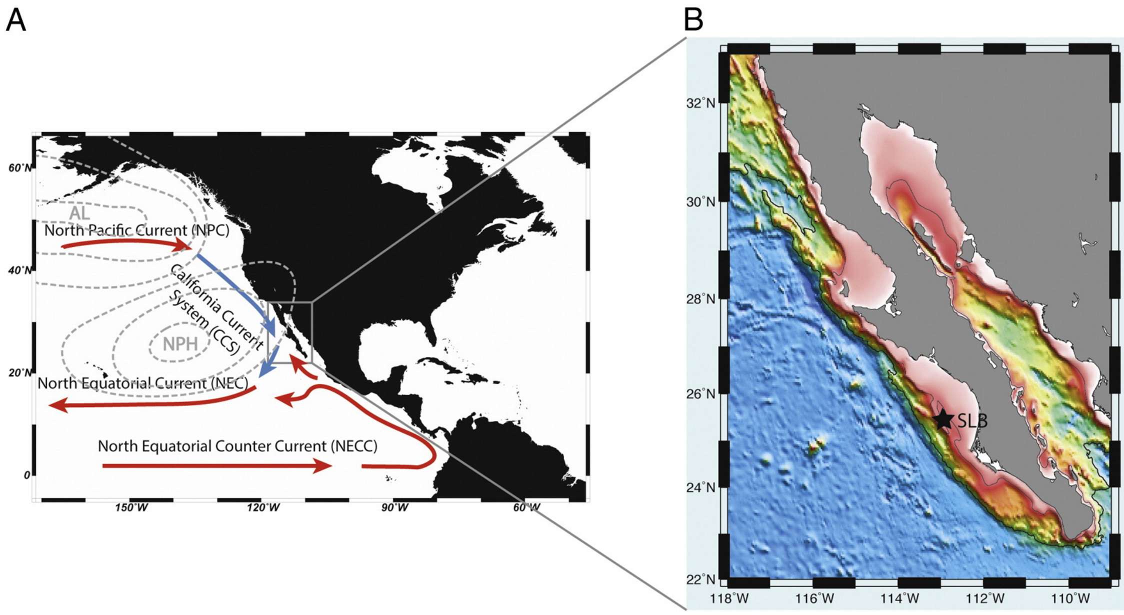

Fig. 1. Location area. A. Map of the North Pacific basin. Red arrows represent warm-water currents; blue arrows cold-water currents. B. Magnification of the study area. A bathymetric profile is represented. The black star is situated at the San Lázaro Basin (SLB) where the MD02-2506-C^2 core was retrieved. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

region (Hood et al., 1990) and the consequent increase in the amount of exported organic carbon deposited on the seafloor during these periods. The intensification of AL during the winter (Bograd et al., 2002) causes a southward migration of the NPH. The NPH in turn controls the southwest winds, thereby favoring the convergence of waters in the EBC onto the continental margin and causing a decrease in the amount of organic carbon reaching the seafloor. This seasonality is further reflected in the annual cycle of sea surface temperatures (SSTs) in this southern domain of the CCS, ranging from 19 °C during the spring to 24 °C in the fall. However, interannual variability (i.e. *El Niño* or *La Niña*) can produce temperatures outside this range (Thunell et al., 1999; Kincaid et al., 2000; Espinosa-Carreon et al., 2004). As a consequence of the high sensitivity of the CCS to atmospheric variability, a high-amplitude variability of the organic carbon exported to the seafloor is to be expected, making the SLB a highly suitable locality to test our DSR-proxy of organic carbon in marine sediments.

The aims of the present studies are as follows: (1) to establish and calibrate a statistical transfer function relating DSR from the visible (400–700 nm) region of the electromagnetic spectrum to the percentage of organic carbon determined by chemically-based analytical techniques in a core transect, (2) to use the transfer function on our entire record to obtain the percentage of organic carbon from DSR, and (3) to evaluate the interdecadal-to-centennial variability of the percentage of organic carbon at our core site in order to monitor past CCS variability during the Mid- and Late-Holocene and their possible teleconnections with the sub-tropical Pacific.

2. Study area and methodology

2.1. Study area

This study is based on a 4.5 m long Calypso Kasten core (MD02-2506-C^2) retrieved from the SLB at a water depth of 545 m (25°12′05 N, 112°43′08 W) during the Marion Dufresne 2002 campaign.

The SLB is situated at the edge of the continental shelf, approximately 45 km west of the Baja California coast (Fig. 1). The depression, formed tectonically, is about 85 km long and 35 km wide and has a maximum depth of 540 m. It has an irregular seaward margin that prevents nearly all the exchange of subsurface waters at depths greater than 100 m entering the basin through a sill depth of 350 m (Esparza-Alvarez et al., 2007).

This location is characterized by relatively high levels of primary production owing to both the advection of the cold and nutrient-rich California Current waters and upwelling episodes, which are most intense during the spring. These processes are responsible for the high production and export of organic matter, opaline and calcitic shells from the mixed layer, which are the source of the light lamina on the sea-floor of the SLB (Soutar and Isaacs, 1974). The combination of both elevated biogenic material export and high terrigenous input through runoff causes high sedimentation rates (>1 m/kyr) (van Geen et al., 2003).

2.2. Age model

The chronostratigraphy of the cores was constructed based on two approaches. The first one involved the correlation of the carbonate stratigraphy of MD02-2506-C^2 with an AMS^{14}C-dated carbonate stratigraphy that we already had for a collection of Kasten cores from the SLB. The second one was constructed with the aid of 4 AMS^{14}C determinations from core MD02-2506-C^2. The samples used for these determinations were freeze-dried after collection, weighed and washed with distilled water and then ultra-sonicated for 20 s. An assortment of different planktic foraminifer species was picked from all samples, and sometimes several contiguous sample depths had to be pooled in order to collect enough planktic foraminifera for an AMS determination (Table 1).

These determinations were carried out at the Lawrence Livermore National Laboratory. We corrected the raw AMS^{14}C ages with the aid of the CALIB5.0 community program (Stuiver et al., 2005), based on the calibration by Hughen et al. (2004). With these two approaches, we confirmed the loss of the first upper centimeters from core MD02-

Table 1
Summary of the ^{14}C ages obtained from planktic foraminifera in core MD02-2506-C^2.

Core name	Depth (cm)	^{14}C age	Min age, BP	Max age, BP	Mean age, BP
MD02-2506-C^2	60–70	1525	680	935	808
MD02-2506-C^2	175–176	2590	1815	2120	1968
MD02-2506-C^2	350–355	4260	3755	4330	4043
MD02-2506-C^2	450–456	5430	5285	5835	5560