Deep-Sea Research II 104 (2014) 335–358

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Influence of the Nazaré Canyon, central Portuguese margin, on late winter coccolithophore assemblages

Catarina Guerreiro [a,b,c,*], Carolina Sá [d], Henko de Stigter [b], Anabela Oliveira [a], Mário Cachão [c,e], Lluïsa Cros [f], Carlos Borges [a], Luis Quaresma [a], Ana I. Santos [a], José-Manuel Fortuño [f], Aurora Rodrigues [a]

[a] Portuguese Hydrographic Institute (IH), Rua das Trinas 49, 1249-093 Lisbon, Portugal
[b] Royal Netherlands Institute for Sea Research (NIOZ), Marine Geology Department, Texel, The Netherlands
[c] Geology Centre of the University of Lisbon, 1749-016 Lisbon, Portugal
[d] Oceanography Centre, Faculty Sciences, University of Lisbon, 1749-016 Lisbon, Portugal
[e] Department of Geology, Faculty Sciences, University of Lisbon, 1749-016 Lisbon, Portugal
[f] Institut de Ciencies del Mar (CSIC), Passeig Marítim de la Barceloneta, 37-49, E-08003 Barcelona, Spain

ARTICLE INFO

Available online 1 October 2013

Keywords:
Living coccolithophores
Chl-a
ENACWst
Submarine canyon

ABSTRACT

This paper presents a first attempt to characterize coccolithophore assemblages occurring in the context of an active submarine canyon. Coccolithophores from the upper-middle sections of the Nazaré Canyon (central Portuguese margin) – one of the largest canyons of the European continental margin – were investigated during a late winter period (9–12 March 2010). Species distributions were analyzed in a multiparameter environmental context (temperature, salinity, turbidity, Chl-a and nutrient concentrations). Monthly averaged surface water Chl-a concentrations between 2006 and 2011 assessed from satellite data are also presented, as a framework for interpreting spatial and temporal distribution of phytoplankton in the Nazaré Canyon. The Nazaré Canyon was observed to act as a conduit for advection of relatively nutrient-poor oceanic waters of ENACWst origin into nearshore areas of the continental shelf (less than 10 km off the coast), whilst at the surface a nutrient-rich buoyant plume resulting from intensive coastal runoff prior and during the beginning of the cruise was spreading in oceanward direction. Two distinct coccolithophore assemblages appear representative for the coast to open-ocean gradient: (1) *Emiliania huxleyi* together with *Gephyrocapsa ericsonii* and *Coronosphaera mediterranea* dominated the more productive assemblage present within coastal-neritic surface waters; and (2) *Syracosphaera* spp. and *Ophiaster* spp. displayed a higher affinity with open-ocean conditions, and also generally a broader vertical distribution. Local "hotspots" of coccolithophore and phytoplankton biomass potentially associated with perturbations of surface water circulation by the canyon are discussed.

1. Introduction

Submarine canyons incising the continental margins are prominent topographic features that modify the coastal circulation. By intensifying shelf-slope exchange of water and organic/inorganic matter they play a key-role in global biogeochemical cycling (e.g. Durrieu de Madron, 1994; Gardner, 1989; Hickey et al., 1986; Monaco et al., 1999; Puig et al., 2003). Narrow canyons tend to have a stronger effect on low-frequency circulation, whereas wider canyons mainly cause bottom flow adjustment along isobaths (Klinck, 1988). Stratification of the water column reduces the canyon's topographic effect on the coastal flow (Hickey, 1997; She and Klinck, 2000).

In the upper water layers (above 100 m), the influence of the canyon is only gentle, with the along-shelf flow turning slightly onshore upstream of the canyon and turning offshore downstream. Closer to the canyon rims (100–200 m) the along-shelf flow is more strongly deflected in onshore direction, turning back on the downstream side of the canyon, with upwelling or downwelling occurring above the rims, depending on the wind direction (She and Klinck, 2000). In the Northern Hemisphere right-bounded flows (i.e. coast to the right, looking downstream) induce downwelling-conditions within the canyon, whereas left-bounded flows favor the occurrence of upwelling (Klinck, 1996; She and Klinck, 2000). Upwelling occurs mostly at the canyon head and downstream rim and adjacent shelf (Allen, 1996; Klinck, 1996; Mendes et al., 2011; She and Klinck, 2000). Under downwelling

* Corresponding author at: Portuguese Hydrographic Institute (IH), Rua das Trinas 49, 1249-093 Lisbon, Portugal. Fax: +351 217500119.
E-mail address: cataguerreiro@gmail.com (C. Guerreiro).

0967-0645/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.dsr2.2013.09.011

conditions, the canyon acts as a trap for converging shelf water (Skliris and Djenidi, 2006).

The intensification of both coast to ocean and vertical water transport within submarine canyons is expected to affect the dynamics of plankton ecosystems in the vicinity of canyons (see Bosley et al., 2004; Hickey, 1995; Kampf, 2006; Ryan et al., 2005, 2010; Skliris et al., 2002; Skliris and Djenidi, 2006). Indeed a strong response of phytoplankton production to canyon flows, and concentration of marine organisms by physical processes within and around canyons were reported from several studies (e.g. Bosley et al., 2004; Macquart-Moulin and Patriti, 1996; Skliris and Djenidi, 2006).

The Nazaré Canyon, located at the central Portuguese margin and one of the largest submarine canyons of Europe, has been relatively intensely explored with regards to its geology, geomorphology, oceanography and benthic biology (e.g. Tyler et al., 2009). Little is known, however, about the plankton communities thriving in this region, and about the canyon's effect on their ecology.

Guerreiro et al. (submitted for publication) observed a relatively higher diversity of coccolith species, including both oceanic and coastal-neritic taxa but with a relative dominance of the latter, in the Nazaré Canyon in comparison to the adjacent shelf/slope regions. This was interpreted as reflecting the exchange of water masses between coastal and oceanic regions through the canyon, as well as the dynamic and nutrient-rich conditions where the coastal species are better adapted to survive. Locally enhanced productivity in the surroundings of the canyon may be related to persistent physical phenomena associated with the canyon such as vertical mixing by solitary internal waves (Quaresma et al., 2007), and/or upwelling in the canyon head (Guerreiro et al., 2009). Evidence for local enhancement of phytoplankton productivity is also provided by observations on phytoplankton pigments reported by Mendes et al. (2011), with maximum values of Chl-a (indicative of phytoplankton in general) near the canyon head and maximum values of 19' hexanoyloxyfucoxantine pigment (indicative of coccolithophores) found in the area north of the canyon.

Here we report the results obtained from a plankton survey on living coccolithophores from the upper-middle Nazaré Canyon, during late winter (9–12 March 2010) (Fig. 1). On the basis of a detailed characterization of the coccolithophore assemblages together with a general characterization of environmental conditions prevailing during the sampling period, the impact of this major submarine canyon on coccolithophores and phytoplankton biomass is discussed.

2. Regional setting

2.1. Oceanography

The central Portuguese continental margin is characterized by a relatively narrow shelf of a few tens of km width, with a maximum of ~70 km where it projects oceanward in the Estremadura promontory, but cut back to very close to shore where it is incised by the Nazaré and Lisbon-Setúbal Canyons. The Douro and Tagus are the most important rivers debouching on the shelf, with relatively minor contribution of continental runoff from other rivers. From the shelf edge located at 160–200 m, a steep upper slope and more gently inclined lower slope incised by numerous gullies and canyons, lead down to the Iberia and Tagus abyssal plains. Surface water circulation along the Portuguese margin is directly dependent on two main current systems transporting water eastwards across the North Atlantic: the North Atlantic Current extending to the north of the Iberian Peninsula, and the Azores Current south of Iberia (Barton, 2001; Peliz et al., 2005; Pollard and Pu, 1985; Saunders, 1982). As the Azores Current extends eastwards, branches of this current loop smoothly into the Portugal Current and further south into the Canary Current. The Portugal Current slowly flows southwards, west of

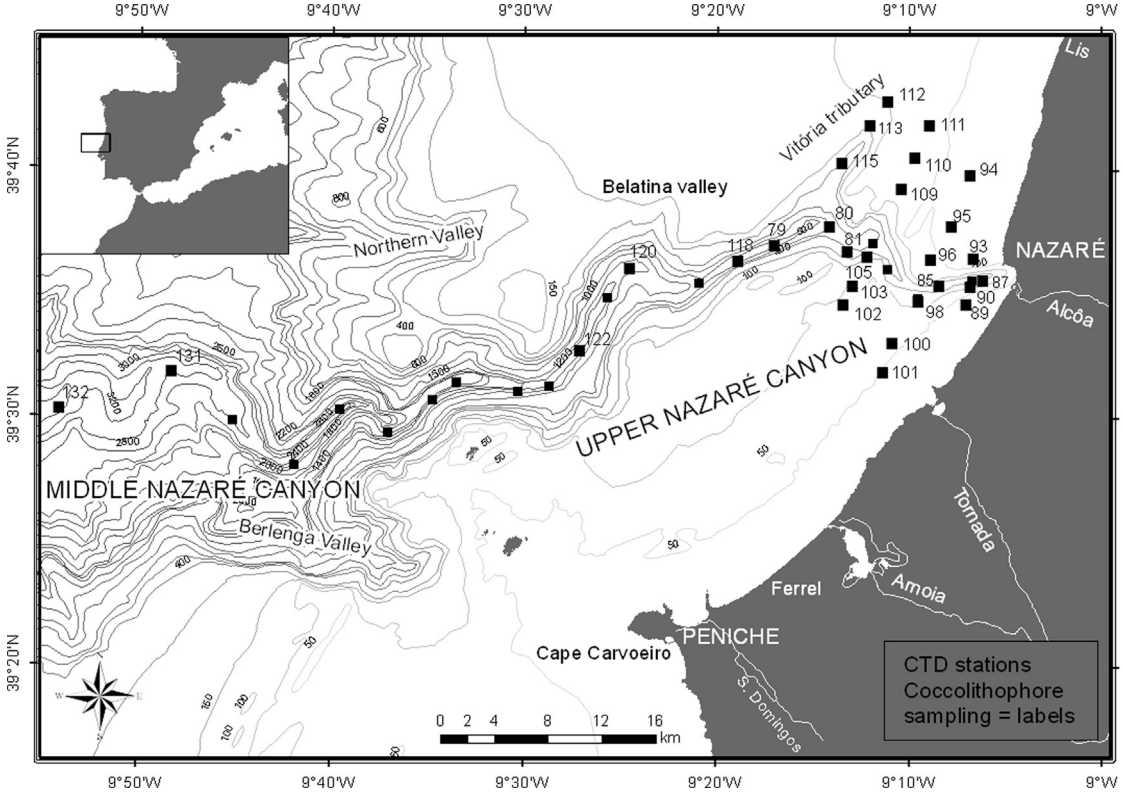

Fig. 1. Geographical location of the study area and investigated CTD casts. Number labeled stations indicate locations where samples for coccolithophore analysis were collected.